Marine Mammal and Sea Turtle Monitoring During Lamont-Doherty Earth Observatory's Marine Seismic Program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January–February 2005

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and

National Marine Fisheries Service, Office of Protected Resources
1315 East-West Hwy, Silver Spring, MD 20910-3282

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by

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LIST OF ACRONYMS AND ABBREVIATIONS

Bf	Beaufort Wind Force
CBD	Center for Biological Diversity
CFR.	(U.S.) Code of Federal Regulations
CIBRA	Centro Interdisciplinare di Bioacustica e Ricerche Ambientali (Univ. of Pavia, Italy)
CITES	Convention on International Trade in Endangered Species
cm	centimeter
CPA	Closest (Observed) Point of Approach
cu. in.	cubic inches
dB	decibels
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
ETPCA	Eastern Tropical Pacific off Central America
ESA	(U.S.) Endangered Species Act
CST	Central Standard Time
$f(0)$	sighting probability density at zero perpendicular distance from survey track; equivalently, 1/(effective strip width)
ft	feet
GI	Generator–Injector
GIS	Geographic Information System
GMT	Greenwich Mean Time
$g(0)$	probability of seeing a group located directly on a survey line
GPS	Global Positioning System
h	hours
hp	horsepower
Hz	Hertz (cycles per second)
IHA	Incidental Harassment Authorization (under U.S. MMPA)
in^3	cubic inches
IUCN	International Union for the Conservation of Nature
kHz	kilohertz
km	kilometer
km^2	square kilometers
km/h	kilometers per hour
kW	kilowatt
K-T	Cretaceous-Tertiary boundary
kt	knots
L-DEO	Lamont-Doherty Earth Observatory (of Columbia University)
µPa	micro Pascal
m	meters
MBB	Multibeam Bathymetric (sonar)
min	minutes
MMO	Marine Mammal (and Sea Turtle) Observer
MMPA	(U.S.) Marine Mammal Protection Act

n	sample size
n.mi.	nautical miles
NMFS	(U.S.) National Marine Fisheries Service
No.	number
NSF	(U.S.) National Science Foundation
OBS	Ocean Bottom Seismometer
PAM	Passive Acoustic Monitoring
PD	Power down of the airguns to one operating airgun
PI	Principal Investigator
pk-pk	peak-to-peak
psi	pounds per square inch
RDT	Rotational Directional Transmission (re Multibeam Sonar)
re	in reference to
rms	root-mean-square
rpm	revolutions per minute
s	seconds
SD	Shut Down of all the airguns not associated with mitigation
s.d.	standard deviation
SEAMAP	SEAMAP Cetacean Monitoring System
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales (the Ministry of the Environment and Natural Resources of Mexico)
SPL	Sound Pressure Level
SZ	Shut Down of all the airguns because of a marine mammal or sea turtle sighting near or within the safety radius
TTS	Temporary Threshold Shift
UNEP	United Nations Environmental Programme
"Useable"	Visual effort or sightings made under the following observation conditions: daylight periods within the study area, ***excluding*** periods 90 s to 6 h after airguns were turned off (post-seismic), nighttime observations, poor visibility conditions (visibility <3.5 km), and periods with Beaufort Wind Force >5 (>2 for cryptic species). Also excluded were periods when the *Ewing*'s speed was <3.7 km/h (2 kt) or with >60º of severe glare between 90º left and 90º right of the bow.
UT	University of Texas, Institute of Geophysics, Austin, TX

EXECUTIVE SUMMARY

Introduction

This document serves to meet reporting requirements specified in an Incidental Harassment Authorization (IHA) issued to Lamont-Doherty Earth Observatory (L-DEO) by the National Marine Fisheries Service (NMFS) on 27 Feb. 2004. The IHA (Appendix A) authorized non-lethal takes of certain marine mammals incidental to a marine seismic survey off the Northern Yucatán Peninsula in the Gulf of Mexico. Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the U.S. Marine Mammal Protection Act (MMPA). Cetaceans exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms) might be sufficiently disturbed to be "taken by harassment". "Taking" would also occur if marine mammals close to the seismic activity experienced a temporary or permanent reduction in their hearing sensitivity, or reacted behaviorally to the airgun sounds in a biologically significant manner.

It is not known whether seismic exploration sounds are strong enough to cause temporary or permanent hearing impairment in any marine mammals or sea turtles that occur close to the seismic source. Nonetheless, NMFS requires measures to minimize the possibility of any injurious effects (auditory or otherwise), and to document the extent and nature of any disturbance effects. In particular, NMFS requires that seismic programs conducted under IHAs include provisions to monitor for marine mammals, and to shut down or power down the airguns when mammals or turtles are detected within designated safety radii. In this project, a power down was a reduction to one operating airgun, whereas a shut down involved the complete cessation of all airguns.

Seismic Program Described

The purpose of the seismic survey was to study the Chicxulub Crater, which is uniquely suited for a seismic investigation into the deformation mechanisms of large-diameter impacts in general, and the physical parameters of the K-T impact in particular. The survey encompassed an area between 21º and 22.5ºN and between 88º and 91ºW in the southern Gulf of Mexico. Water depths within the study area were <100 m (<328 ft). The study took place in the Exclusive Economic Zone (EEZ) of Mexico. The R/V *Maurice Ewing* departed Colon, Panama, on 7 Jan. 2005 and arrived in the study area on 11 Jan. The study was concluded on 20 Feb. 2005, when the vessel arrived in Progreso, Mexico.

This seismic survey used an array of 20 Bolt airguns with a total discharge volume of 6970 in^3. The airgun array was deployed from the *Ewing*. A 6-km streamer containing hydrophones was also towed behind the *Ewing* to receive the returning seismic acoustic signals. In addition, Ocean Bottom Seismometers (OBSs) were deployed by the *Ewing* to record airgun sounds. A multibeam bathymetric sonar and a lower energy 3.5 kHz sub-bottom profiler were operated from the *Ewing* throughout all or much of the survey. As part of the marine mammal monitoring effort, a 300-m hydrophone array was also towed behind the *Ewing* to conduct passive acoustic monitoring (PAM) for vocalizing cetaceans.

Monitoring and Mitigation Description and Methods

Six trained marine mammal observers (MMOs) were aboard the *Ewing* throughout the period of operations for visual and acoustic monitoring. The primary purposes of the monitoring and mitigation effort were the following: ***(A)*** Document the occurrence, numbers and behaviors of marine mammals and sea turtles near the seismic source. ***(B)*** Implement a power down or shut down of the airguns when marine mammals or turtles were sighted near or within the designated safety radii. ***(C)*** Monitor for marine mammals and sea turtles before and during ramp-up periods.

At least one MMO watched for marine mammals and sea turtles at all times while airguns operated during daylight periods, and when the vessel was underway but the airguns were not firing. Seismic operations were not permitted at night based on mitigation measures required by the Mexican government, in particular the General Directorate of the Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT, the Ministry of the Environment and Natural Resources of Mexico).

The visual MMOs used 7 x 50 binoculars, 25 x 150 Big-eye binoculars, and the naked eye to scan the surface of the water around the vessel for marine mammals and sea turtles. The distance from the observer to the sighting was estimated using reticles on the binoculars. MMOs also conducted PAM during daytime seismic operations. The primary purpose of the acoustic monitoring was to aid visual observers by detecting vocalizing cetaceans. The acoustic MMO listened with headphones or speakers to sounds received from the hydrophone array and simultaneously monitored a real-time spectrogram display. When a calling cetacean was detected, the acoustic MMO communicated the presence of the animal to the visual MMOs. When a marine mammal or turtle was detected within or approaching the safety radius, the MMO contacted the airgun operators to request a power down or shut down of the airguns.

Primary mitigation procedures, as required by the IHA, included the following: ***(A)*** Ramp ups consisting of a gradual increase in the volume of the airgun array, whenever the airguns were started after periods without airgun operations or after prolonged operations with one airgun. ***(B)*** Immediate power downs or shut downs of the airguns whenever marine mammals or sea turtles were detected within or about to enter the safety radius. The safety radii during the survey were based on the distances within which the received levels of airgun sounds were expected to diminish to 180 dB re 1 μPa (rms) in shallow water (<100 m). For the 20-airgun array, the safety radius for cetaceans and sea turtles was 3500 m.

Monitoring Results

The study area for the purposes of marine mammal and sea turtle data analyses was the actual seismic survey area plus the portions of the transits from Colon, Panama, and to Progreso, Mexico, that lie within the Caribbean Province of the Atlantic Trade Wind Biome. About 400 km of effort near Panama and outside this biome were excluded from analyses; no animals were seen during that effort.

The *Ewing* traveled a total of 9476 km within the study area (Table ES.1; Fig. 1.1). The airguns operated only during daylight along 20% of the total ship track. About 79% of seismic operations were conducted with the 20-airgun array. The actual number of kilometers traveled during seismic periods was lower than anticipated in the IHA Application and EA (1892 vs. 3313 km, respectively); this was primarily because nighttime operations proposed in the IHA Application and EA were not permitted by SEMARNAT. Ramp ups of the airguns occurred on 56 occasions, including 16 ramp ups from 1 airgun to the full 20 airgun array, and 40 ramp ups from no airguns (start ups). MMOs were on visual watch during all start ups and ramp ups. No start ups or ramp ups were conducted at night.

In total, 4281 km of visual observations and 2935 km of PAM were conducted (Table ES.1). MMOs were on visual watch for all airgun operations, and PAM occurred during >99% of all seismic periods. Nearly all visual (>99%) and PAM (94%) effort occurred during daylight. The remaining PAM effort occurred near dawn and dusk.

Analyses of cetacean and sea turtle behavior and density data focused on sightings and survey effort in the study area during "useable" survey conditions, which represented 83% of the total visual effort (Table ES.1). "Useable" effort excluded periods 90 s to 6 h after airguns were turned off (post-seismic), poor visibility (<3.5 km) conditions, and periods with Beaufort Wind Force >5. Also excluded were periods when the *Ewing*'s speed was <3.7 km/h (2 kt) or with >60° of severe glare between 90º left and right of the bow. About 78% of all PAM effort was concurrent with useable daylight visual effort.

Sea Turtles

Two of the five species of sea turtles expected to occur in the Gulf of Mexico were identified during the cruise: the hawksbill and loggerhead turtles. The Chicxulub cruise did not overlap with the sea turtle nesting season. During the study, 29 single sea turtles were seen (Table ES.1). One additional sea turtle was found dead, entangled in fishing gear, and NMFS and SEMARNAT were notified of the occurrence on that same day.

Sea turtles were distributed throughout the seismic survey area. Most (76%) turtles were seen when airguns were silent (n = 22; Table ES.1). Of the 29 turtles seen, 72% were sighted during "useable" survey conditions (Table ES.1). In general, turtle sightings were too infrequent for detailed interpretation of potential effects of seismic operations. "No movement" and "logging" were the most commonly observed turtle movement and behavior, respectively, during both seismic and non-seismic conditions. The mean closest observed points of approach of turtles were similar during non-seismic vs. seismic conditions (290 vs. 284 m, respectively, n = 14 vs. 7 groups).

A total of four shut downs and three power downs were implemented during the cruise because of sea turtles (Table ES.1). All shut downs occurred when a turtle was first sighted within the 180 dB sound radius; there were no cases when a full shut down was preceded by an initial power down. All seven of these turtle sightings were at radii <1100 m, well within the 180 dB safety radius of 3500 m applicable during seismic operations in shallow water (<40 m). Six of the seven turtles were seen <200 m from the operating airguns before the airguns were powered or shut down. Given these factors, all seven of the turtles first sighted within the safety radius likely would have received sound levels >180 dB if they dove. Ramp ups were delayed three times because of the proximity of sea turtles.

Cetaceans

Only the bottlenose and Atlantic spotted dolphin are known to occur regularly in the shallow (<100 m) waters of the study area; in fact, these were the only marine mammal species identified in the seismic survey area proper. One group of pantropical spotted dolphins was seen during transit in deep water. Within the study area, including transits, ~119 individual cetaceans (all delphinids) were sighted in 24 groups: eight bottlenose, seven Atlantic spotted, one pantropical spotted, and eight unidentified dolphin groups (Table ES.1). No injured cetaceans potentially associated with the operations were sighted at any time during the cruise. A total of 13 acoustic detections were made during the cruise: 11 unidentified dolphin and 2 bottlenose dolphin detections. Three of the 13 acoustic detections were matched with visual sightings.

In general, the relatively small numbers of sightings (n = 24) and acoustic detections (n = 13) did not allow meaningful interpretation of sighting rates and behavior during seismic vs. non-seismic periods. However, observed trends are similar to those seen during previous *Ewing* and other seismic surveys: ***(A)*** Densities of cetaceans estimated from visual observations during non-seismic periods were ~8 times higher than those during seismic periods. Although the number of sightings was too low for meaningful statistical analysis, the difference in densities was likely due to movements of cetaceans beyond visual range (>3 km) of the MMOs on the *Ewing* during seismic periods. ***(B)*** The acoustic detection rates during non-seismic periods were also higher than during seismic periods. ***(C)*** Delphinids tended to be seen farther from the observation vessel during seismic than during non-seismic periods. ***(D)*** Acoustic detection rates were higher than visual detection rates during non-seismic periods, which is typical for joint visual/acoustic surveys. ***(E)*** PAM results (and some previous studies) indicate that at least some cetaceans call in the presence of airgun pulses. ***(F)*** Four delphinid groups were observed to bowride, in all cases during non-seismic periods.

Number of Marine Mammals Present and Potentially Affected

During this project, the "safety radii" called for by NMFS for cetaceans were the best estimates of the 180-dB radii for a 20-airgun array with a slightly larger volume (8600 in^3) than was actually used during this study (6970 in^3). All 24 marine mammal sightings made during the cruise were of delphinids, which are known to be less sensitive to low-frequency sounds than baleen whales. The airguns were shut down once and powered down four times because of the presence of five different delphinid groups (involving seven dolphins) within or near the designated safety zone (Table ES.1). These dolphins were first observed in the safety zone, and were very likely exposed to airgun sounds ≥180 dB before mitigation measures could be implemented.

Any large cetaceans that might have been exposed to received sound levels ≥160 dB re 1 µPa (rms), and delphinids exposed to received levels of ≥170 dB re 1µPa, were assumed to have been potentially disturbed during the seismic study. Based on direct observations, a total of 13 delphinids in 7 groups were seen within the ≥160 dB radius, all of which were also sighted within the ≥170 dB radius around the operating airguns. The 170 dB radius is considered a more realistic disturbance criterion for delphinids. All of these dolphins were presumably exposed to airgun sounds ≥170 dB given the shallow water where they were seen.

Minimum and maximum numbers of cetaceans exposed to ≥160 and ≥170 dB re 1 µPa (rms) were also estimated based on densities of cetaceans derived by line-transect procedures. These estimates allowed for animals not seen by MMOs. A minimum of 542 individual delphinids might have been in the areas about to be exposed to airgun sounds with received levels ≥170 dB re 1 µPa (rms), based on observations during non-seismic periods. Thus, based on this approach, ~542 cetaceans (all dolphins) might have been exposed to sound levels that could have disturbed them. Similarly, ~899–2674 delphinids are estimated to have been within the areas exposed to ≥160 dB. These estimates based on actual density data are lower than the "harassment takes" estimated prior to the survey. The maximum estimate of the number of exposures to ≥160 dB (n = 2674) is only about 15% of the potential "take" estimated in the IHA Application, and the minimum estimate of 899 individuals is only about 5% of the estimated take.

In summary, available evidence is consistent with the expectation that cetaceans would show some avoidance of the seismic vessel within the 160–170 dB radii (i.e., ~7–12 km). Some avoidance was to be expected given the relatively large sound source used in this project as compared with many previous *Ewing* and other seismic surveys. In any event, the estimated number of cetaceans potentially affected by L-DEO's survey was much lower than that authorized by NMFS. Given this, and the mitigation measures that were applied, the effects were very likely localized and transient, with no significant impact on either individual cetaceans or their populations.

TABLE ES.1. Summary of *Ewing* operations, observer and passive acoustic monitoring (PAM) effort, and marine mammal and sea turtle sightings during the Chicxulub seismic survey, 7 Jan.–20 Feb. 2005, southern Gulf of Mexico.

	Non-Seismic			Seismic			
	Useable	**Other**	**Post Seismic**	**Useable[a]**	**Other**	**Total Useable[a]**	**Total**
Operations in h							
Ewing Nighttime	-	428	111	-	-	-	539
Ewing Daylight	147	47	54	201	4	348	453
***Ewing* Total**	**147**	**475**	**165**	**201**	**4**	**348**	**992**
Observer Nighttime	-	-	-	-	-	-	-
Observer Daylight	139	43	48	201	4	340	434
Observer Total	**139**	**43**	**48**	**201**	**4**	**340**	**434**
PAM Nighttime	-	14	4	-	-	-	19
PAM Daylight	51	1	48	200	4	251	303
PAM Total	**51**	**15**	**52**	**200**	**4**	**251**	**322**
Operations in km							
Ewing Nighttime	-	3987	1011	-	-	-	4998
Ewing Daylight	1824	283	479	1855	37	3679	4478
***Ewing* Total**	**1824**	**4270**	**1490**	**1855**	**37**	**3679**	**9476**
Observer Nighttime	-	-	-	-	-	-	-
Observer Daylight	1707	275	406	1855	37	3562	4281
Observer Total	**1707**	**275**	**406**	**1855**	**37**	**3562**	**4281**
PAM Nighttime	-	127	42	-		-	168
PAM Daylight	435	7	441	1847	37	2282	2767
PAM Total	**435**	**134**	**482**	**1847**	**37**	**2282**	**2935**
No. Cetacean Sightings (Indiv.)	13 (80)	1 (10)	3 (16)	6 (12)	1 (1)	19 (92)	24 (119)
No. Cetacean Acoustic Detections	4	3	1	5	-	9	13
No. Sea Turtle Sightings (Indiv.)	14 (14)	2 (2)	6 (6)	7 (7)	-	21 (21)	29 (29)[b]
No. Power/ Shut Downs (PD/SZ) for Cetaceans	-	-	-	5	-	5	5
No. PD or SZ for Sea Turtles	-	-	-	7	-	7	7
PD or SZ Total	**-**	**-**	**-**	**12**	**-**	**12**	**12**

[a] See *Acronyms and Abbreviations* for the definition of "useable" effort.

[b] A single dead sea turtle seen during the cruise was found entangled in fishing gear and was excluded from this table and analyses. The observers concluded that the turtle had been dead for an extended period and had not been injured or killed by the seismic operations in progress at the time.

1. INTRODUCTION

Lamont-Doherty Earth Observatory (L-DEO) conducted a marine seismic study from 7 Jan. to 20 Feb. 2005 off the Yucatán Peninsula in the southern Gulf of Mexico (Fig. 1.1). The project was conducted aboard the R/V *Maurice Ewing* which is owned by the National Science Foundation (NSF) and operated by L-DEO. The purpose of the seismic survey was to study the Chicxulub Crater. The crater is uniquely suited for a seismic investigation into the deformation mechanisms of large-diameter impacts in general, and the physical parameters of the Cretaceous-Tertiary (K-T) impact in particular. The study used an airgun array consisting of 20 Bolt airguns with a total discharge volume of 6970 in^3 as the energy source. The geophysical investigation was under the direction of the Principal Investigators (PIs) Dr. Penny Barton of the University of Cambridge, U.K., and Dr. Sean Gulick of the University of Texas (UT) Institute of Geophysics.

Marine seismic surveys emit strong sounds into the water (Greene and Richardson 1988; Tolstoy et al. 2004a,b), and have the potential to affect marine mammals, given the known auditory and behavioral sensitivity of many such species to underwater sounds (Richardson et al. 1995; Gordon et al. 2004). The effects could consist of behavioral or distributional changes, and perhaps (for animals close to the sound source) temporary or permanent reduction in hearing sensitivity. Either behavioral/distributional effects or (if they occur) auditory effects could constitute “taking” under the provisions of the U.S. Marine Mammal Protection Act (MMPA) and the U.S. Endangered Species (ESA) Act, at least if the effects are considered to be “biologically significant”.

Numerous species of cetaceans inhabit the southern Gulf of Mexico, mainly various species of dolphins and other toothed whales. Sea turtles are also of concern in the area, including the endangered leatherback and hawksbill turtles, and the threatened loggerhead, green, and olive ridley sea turtles. Although Bryde’s and some other baleen whales, along with sperm whales, occur in the southern Gulf of Mexico, neither they nor pinnipeds occur regularly in the shallow (<100 m) waters of the southern Gulf of Mexico where the study took place.

On 8 Oct. 2003, L-DEO requested that the National Marine Fisheries Service (NMFS) issue an Incidental Harassment Authorization (IHA) to authorize non-lethal “takes” of marine mammals incidental to the airgun operations off the northern Yucatán Peninsula, Gulf of Mexico (LGL Ltd. 2003a). The IHA was requested pursuant to Section 101(a)(5)(D) of the MMPA. An Environmental Assessment (EA) was also written to evaluate the potential impacts of the marine seismic survey in the southern Gulf of Mexico (LGL Ltd. 2003b). That EA was adopted by NSF, the federal agency sponsoring this seismic survey. The IHA was issued by NMFS on 27 Feb. 2004 (Appendix A).

In addition to the mitigation and monitoring requirements of the IHA, the Mexican government required further mitigation measures for marine mammals and sea turtles during the Chicxulub study. This included restricting airgun operations to daylight periods. This was the second time during an L-DEO seismic cruise that no seismic operations were permitted during darkness; the first time was during L-DEO’s calibration study of the *Ewing*’s airgun array in the northern Gulf of Mexico in late spring 2003 (Smultea et al. 2003).

The IHA authorized “potential take by harassment” of marine mammals during the seismic cruise described in this report. The cruise occurred from 7 Jan. to 20 Feb. 2005. The first and last days of seismic operations occurred on 21 Jan. and 17 Feb., although a brief bout (~1 h) of seismic testing occurred on 14 Jan. The ship left Colon, Panama, on 7 Jan. and arrived in the study area 11 Jan. The study was concluded and the vessel arrived in Progreso, Mexico, on 20 Feb.

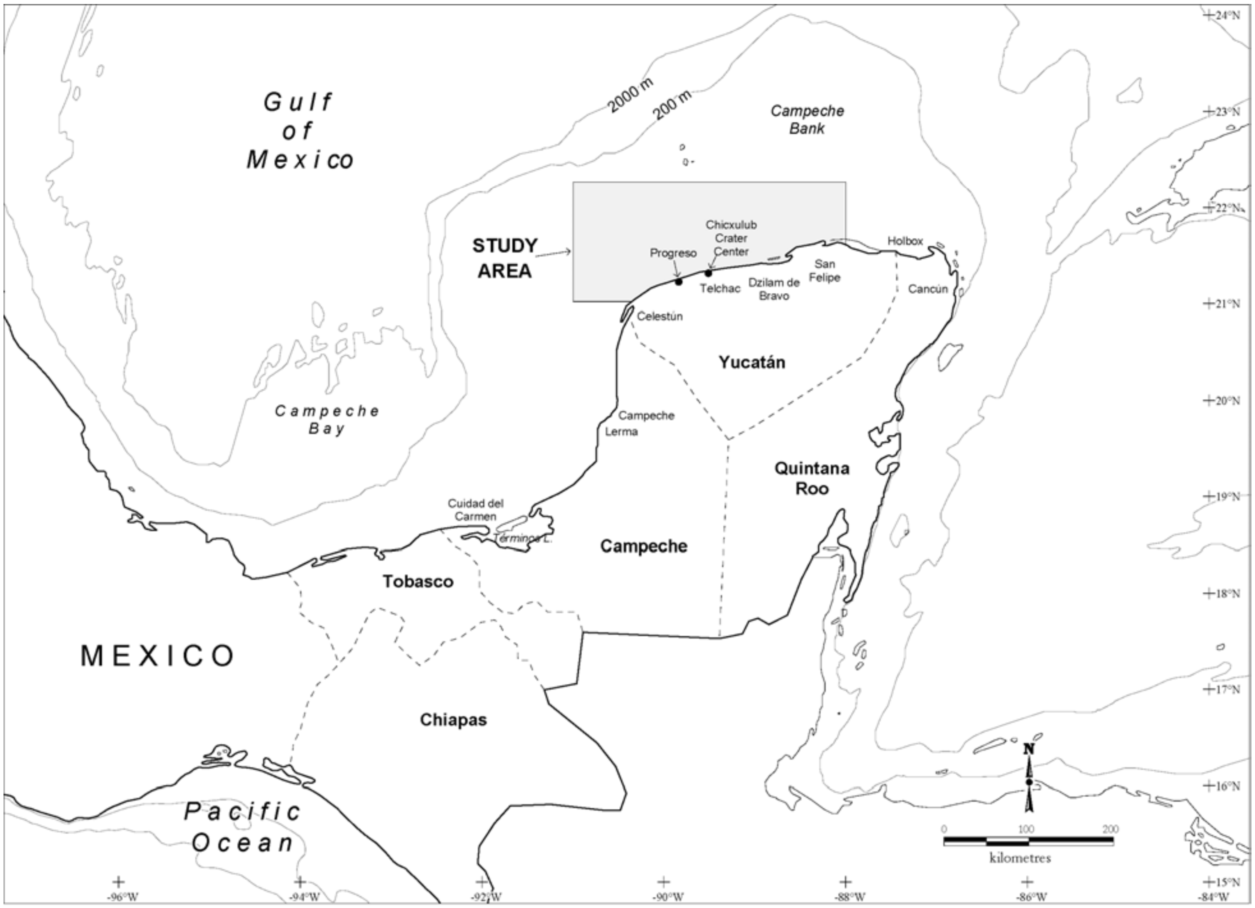

FIGURE 1.1. The Chicxulub seismic study area north of the Yucatán Peninsula in the Gulf of Mexico.

This document serves to meet reporting requirements specified in the IHA. The primary purposes of this report are to describe the seismic survey in the southern Gulf of Mexico, to describe the associated marine mammal (and sea turtle) monitoring and mitigation programs and their results, and to estimate the numbers of marine mammals potentially affected by the project.

Incidental Harassment Authorization

IHAs issued to seismic operators include provisions to minimize the possibility that marine mammals close to the seismic source might be exposed to levels of sound high enough to cause hearing damage or other injuries. During this project, sounds were generated by the airguns used during the seismic study, a multibeam bathymetric (MBB) sonar, a sub-bottom profiler, and by general vessel operations. No serious injuries or deaths of marine mammals (or sea turtles) were anticipated from the seismic survey, given the nature of the operations and the mitigation measures that were implemented, and no injuries or deaths were attributed to the seismic operations. Nonetheless, the seismic survey operations described in Chapter 2 had the potential to "take" marine mammals by harassment. Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the MMPA. Appendix B provides further background on the issuance of IHAs relative to seismic operations and "take".

Under current NMFS guidelines (e.g., NMFS 2000), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which the received pulse levels are ≥180 dB re 1 µPa (rms)[1] for cetaceans and ≥190 dB re 1 µPa (rms) for pinnipeds. Those safety radii are based on an assumption that seismic pulses received at lower received levels are unlikely to injure these mammals or impair their hearing abilities, but that higher received levels *might* have some such effects. The mitigation measures required by IHAs are, in large part, designed to avoid or minimize the numbers of cetaceans and pinnipeds exposed to sound levels exceeding 180 and 190 dB (rms), respectively. In addition, for this project, NMFS specified a safety (shut-down) criterion of 180 dB for sea turtles.

Disturbance to marine mammals could occur at distances beyond the safety (=shut down) radii if the mammals were exposed to moderately strong pulsed sounds generated by the airgun array or perhaps sonar (Richardson et al. 1995). NMFS assumes that marine mammals exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms) are likely to be disturbed appreciably. That assumption is based mainly on data concerning behavioral responses of baleen whales, as summarized by Richardson et al. (1995) and Gordon et al. (2004). Dolphins and pinnipeds are generally less responsive (e.g., Stone 2003; Gordon et al. 2004), and 170 dB (rms) may be a more appropriate criterion of behavioral disturbance for those groups (LGL Ltd. 2003a,b). In general, disturbance effects are expected to depend on the species of marine mammal, the activity of the animal at the time, its distance from the sound source, and the received level of the sound and the associated water depth. Some individuals respond behaviorally at received levels somewhat below the nominal 160 or 170 dB (rms) criteria, but others tolerate levels somewhat above 160 or 170 dB without reacting in any substantial manner.

A notice regarding the proposed issuance of an IHA for the survey off the northern Yucatán Peninsula, Gulf of Mexico, was published by NMFS in the *Federal Register* on 16 Dec. 2003 and public comments were invited (NMFS 2003). The Animal Welfare Institute, the Center for Biological Diversity (CBD) and an individual submitted comments (NMFS 2004).

On 27 Feb. 2004, L-DEO received the IHA that had been requested for the Chicxulub project, and on 29 Mar. 2004 NMFS published a second notice in the *Federal Register* to announce the issuance of the IHA (NMFS 2004). The second notice responded to comments received by NMFS, and provided additional information concerning the IHA and any changes from the originally proposed IHA. A copy of the issued IHA is included in this report as Appendix A.

The IHA was granted to L-DEO on the assumptions that

- the numbers of marine mammals potentially harassed (as defined by NMFS criteria) during seismic operations would be "small",
- the effects of such harassment on marine mammal populations would be negligible,
- no marine mammals would be seriously injured or killed, and
- the agreed upon monitoring and mitigation measures would be implemented.

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[1] "rms" means "root mean square", and represents a form of average across the duration of the sound pulse as received by the animal. Received levels of airgun pulses measured on an "rms" basis are generally 10–12 dB lower than those measured on the "zero-to-peak" basis, and 16–18 dB lower than those measured on a "peak-to-peak" basis (Greene 1997; McCauley et al. 1998, 2000). The latter two measures are the ones commonly used by geophysicists. Unless otherwise noted, all airgun pulse levels quoted in this report are rms levels.

Mitigation and Monitoring Objectives

The objectives of the mitigation and monitoring program were described in detail in L-DEO's IHA Application (LGL Ltd. 2003a) and in the IHA issued by NMFS to L-DEO (Appendix A). Explanatory material about the monitoring and mitigation requirements was published by NMFS in the *Federal Register* (NMFS 2003, 2004). Additional monitoring and mitigation procedures were required by the Mexican authorities, in particular the General Directorate of the Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT, the Ministry of the Environment and Natural Resources of Mexico).

The main purpose of the mitigation program was to avoid or minimize potential effects of L-DEO's seismic survey on marine mammals and sea turtles. This required that L-DEO detect marine mammals and sea turtles within or about to enter the safety radius, and in such cases initiate an immediate power down (or shut down if necessary) of the airguns. A power down involves reducing the source level of the operating airguns, generally by ceasing the operation of all but one airgun. A shut down involves ceasing the operation of all airguns. An additional mitigation objective was to detect marine mammals or sea turtles within or near the safety radii prior to starting the airguns, or during ramp up toward full power. In these cases, the start of airguns was to be delayed or ramp up discontinued until the safety radii was free of marine mammals or sea turtles (see Appendix A and Chapter 3).

The primary objectives of the monitoring program were as follows:

1. Provide real-time sighting data needed to implement the mitigation requirements.
2. Use real-time passive acoustic monitoring (PAM) to monitor for vocalizing cetaceans and to notify visual observers of nearby cetaceans.
3. Estimate the numbers of marine mammals potentially exposed to strong seismic pulses.
4. Determine the reactions (if any) of potentially exposed marine mammals and sea turtles.

Specific mitigation and monitoring objectives identified in the IHA are shown in Appendix A. Mitigation and monitoring measures that were implemented during the Chicxulub cruise are described in detail in Chapter 3.

Report Organization

The primary purpose of this report is to describe the 2005 Chicxulub seismic study that was conducted off the northern Yucatán Peninsula, Gulf of Mexico, including the associated monitoring and mitigation programs, and to present results as required by the IHA (see Appendix A). This report includes five chapters:

1. Background and introduction (this chapter);
2. Description of the seismic study;
3. Description of the marine mammal and sea turtle monitoring and mitigation requirements and methods, including safety radii;
4. Results of the marine mammal monitoring program, including estimated numbers of marine mammals potentially "taken by harassment", and
5. Results of the sea turtle monitoring program.

Those chapters are followed by Acknowledgements and Literature Cited sections.

In addition, there are nine Appendices. Details of procedures that are more-or-less consistent across L-DEO's recent seismic surveys are provided in the Appendices and are only summarized in the main body of this report. The Appendices include

A. a copy of the IHA issued to L-DEO for this study;

B. background on development and implementation of safety radii;

C. characteristics of the *Ewing*, its airgun array, and its sonars;

D. details on visual and acoustic monitoring, mitigation, and data analysis methods;

E. conservation status and densities of marine mammals in the project region;

F. monitoring effort and list of cetaceans seen or heard during this cruise;

G. cetacean sightings with power downs and shut downs during the Chicxulub cruise;

H. additional supporting details re numbers of marine mammals exposed to seismic sounds; and

I. sea turtle sightings during the Chicxulub cruise.

2. CHICXULUB SEISMIC SURVEY DESCRIBED

The *Ewing* towed a 20-airgun array and a 6-km hydrophone streamer during this seismic study. The *Ewing* also deployed a total of 25 Ocean Bottom Seismometers (OBS) in the study area. The streamer and the OBSs were used to receive the returning acoustic signals. In addition, a 300-m SEAMAP Cetacean Monitoring System (SEAMAP) consisting of a four-channel hydrophone array was towed behind the *Ewing* to detect calling cetaceans via PAM methods (see Chapter 3).

Procedures used to obtain seismic data during the Chicxulub study were similar to those used during previous seismic surveys by L-DEO, e.g., off the coast of Newfoundland in the North Atlantic (Holbrook et al. 2003) and in the SE Caribbean (Smultea et al. 2004). The Chicxulub study used conventional seismic reflection techniques to characterize the earth's crust, including a towed airgun array as the energy source, and a towed hydrophone streamer and OBSs as the receiver system. In addition, sonars were used to map the bathymetry and sub-bottom conditions to obtain data needed for the geophysical studies.

The following sections briefly describe the seismic survey, the equipment used for the study, and its mode of operation, insofar as necessary to satisfy the reporting requirements of the IHA (Appendix A). More detailed information on the *Ewing* and the equipment is provided in Appendix C.

Operating Areas, Dates, and Navigation

The Chicxulub seismic survey occurred between 21º and 22.5ºN and between 88º and 91ºW off the northern Yucatán Peninsula, Mexico (Fig. 1.1). Water depth within the seismic survey area was <100 m, and the entire seismic study was conducted in the Exclusive Economic Zone (EEZ) of Mexico. The *Ewing* departed Colon, Panama, on 7 Jan. 2005 and arrived near the seismic study area off the coast of Mexico on 11 Jan. The *Ewing* conducted a brief period (~1 h) of seismic testing on 14 Jan. Actual seismic study operations commenced in this area on 20 Jan. and occurred intermittently on ~23 days. The last airgun operations were conducted on 17 Feb. 2005. Airgun operations occurred only during daylight periods. The *Ewing* arrived in Progreso, Mexico, on 20 Feb. 2005. A chronology of the study is presented in Table 2.1. A summary of the total distances traveled by the *Ewing* during the Chicxulub study, distinguishing periods with and without seismic operations, is presented in Table ES.1.

Throughout the study, position, speed, and activities of the *Ewing* were logged digitally every minute. In addition, the position of the *Ewing,* water depth, and information on the airgun array were logged for every airgun shot while the *Ewing* was on a seismic line and collecting geophysical data. The geophysics crew kept a written log of events, as did the marine mammal and turtle observers (MMOs) while on duty. The MMOs also recorded the number and volume of airguns that were firing when the *Ewing* was offline (e.g., turning from one line to the next) or was online but not recording data (e.g., during airgun or computer problems).

Airgun Array Characteristics

The 20-airgun array and the hydrophone streamer were towed by the *Ewing* along predetermined survey lines in the study area (Fig. 2.1). The airgun array consisted of 20 Bolt airguns, and the airguns were spaced across an approximate area of 35 m (across track) by 9 m (along track) (Fig. 2.2). The 20 Bolt airguns varied in volume from 80 to 875 in^3, and the array had a total discharge volume of 6970 in^3. The 20-airgun array used during the Chicxulub study was slightly smaller than the typical L-DEO 20-airgun configuration (discharge total volume ~8600 in^3) used in some past L-DEO seismic studies.

TABLE 2.1. Chronology in Greenwich Mean Time (GMT) of events during the Jan.– Feb. 2005 Chicxulub seismic study off the northern Yucatán Peninsula.

Date in 2005	Time	Event Description
05 Jan		*Ewing* was scheduled to leave Colon, Panama, but departure was delayed; had to wait for Mexican MMOs
06 Jan		Waited for Mexican MMOs
07 Jan	19:31	Left Colon, Panama, en route to study area with 1 Mexican MMO; visual observations started
08 Jan		Transit to study area
09 Jan		Transit to study area
10 Jan		Transit to study area
11 Jan	19:30	Arrived in study area; had to delay operations to wait for 2 more Mexican MMOs and a Naval Officer
12 Jan		No visual observations; vessel stayed in same location all day waiting for Mexican MMOs to arrive
13 Jan		No visual observations; vessel still waiting in same location
14 Jan		Conducted ~1 h of seismic testing within the seismic study area
14 Jan		Resumed visual observations; vessel headed to Progreso to pick up 2 Mexican MMOs
14 Jan	15:29	Port of Progreso was closed due to weather; could not pick up Mexican MMOs
15 Jan		Going to Progreso again, started early in the morning to pick up MMOs
15 Jan	13:53	Arrived in Progreso to pick up Mexican MMOs
15 Jan	16:30	Departed Progreso with 2 more Mexican MMOs
15 Jan	19:22	Deployed first OBS
16 Jan		Still deploying OBSs
17 Jan	12:49	Finished deploying OBSs
17 Jan	14:26	Started to deploy streamer
17 Jan		Could not start operations until SEMARNAT clarified safety radius discrepancy in conditions document
18 Jan	12:08	Finished deploying streamer; waiting on clarification from SEMARNAT regarding safety radius and sea state.
18 Jan	15:30	Received clarification from SEMARNAT regarding 180 dB radius
18 Jan	18:33	Started PAM; no seismic operations conducted due to high winds
18 Jan	20:00	No seismic operations until receipt of official letter from SEMARNAT regarding safety radius
19 Jan		Received letter from SEMARNAT regarding safety radius; still need clarification regarding sea state
20 Jan	22:45	Started seismic operations; received clarification from SEMARNAT regarding sea state (see Chapter 3 text)
21 Jan	12:45	Start second day of airgun operations
31 Jan		Streamer retrieved due to shallow water; seismic operations continue
01 Feb		Seismic operations without streamer
02 Feb	21:30	Retrieved airguns and PAM hydrophone; started retrieving OBSs
03 Feb		Retrieving and redeploying OBSs
04 Feb		Retrieving and redeploying OBSs
05 Feb		Redeployed streamer over night
05 Feb	13:00	Started PAM again
05 Feb	14:00	Finished OBS work; started seismic operations again
14 Feb	3:00	Grounded on reef, recovered all equipment including PAM

15 Feb		No seismic operations, divers inspecting vessel
16 Feb		No seismic operations, divers inspecting vessel
17 Feb	12:43:00	Started seismic again and PAM monitoring
17 Feb	22:47:28	Terminated seismic operations due to legal issues; all equipment recovered, including PAM
18 Feb		No seismic, retrieving OBSs
19 Feb		No seismic, retrieving OBSs
20 Feb		No seismic, retrieving OBSs
20 Feb	19:10:00	Arrived in Progreso, Mexico

Compressed air supplied by compressors aboard the source vessel powered the airgun array. Seismic pulses were emitted at intervals of ~20 s while the *Ewing* traveled at an average speed of ~8.3 km/h (4.5 kt). The 20-s spacing corresponded to a shot interval of ~50 m. During operations, the airguns were suspended in the water from air-filled floats and were oriented horizontally, ~7 m below the water surface (see Appendix C). The characteristics of the 20-airgun array used during the study are summarized in Table 2.2.

The nominal source level for downward propagation of low-frequency energy of the 20-airgun array is shown in Table 2.2. The nominal source level would be somewhat higher if the small amount of energy at higher frequencies were considered. Because the actual source is a distributed sound source (20 airguns) rather than a single point source, the highest sound level measurable at any location in the water will be less than the nominal source level (Caldwell and Dragoset 2000). Also, because of the directional nature of the sound from the airgun array, the effective source level for sound propagating in some near-horizontal directions will be lower. The source level on the rms basis used elsewhere in this report would be lower, but source levels of airguns are not normally determined on an rms basis by airgun manufacturers or geophysicists.

Ewing Line Changes

When the *Ewing* turned from the end of one survey line to the start of the next, it was necessary to make a slow turn to avoid possible entanglement of the 6-km-long hydrophone streamer towed behind the vessel. In addition, two to four airguns were removed from the water during turns from one line to the next to avoid entanglement of the airguns; as a result, the number of airguns firing was reduced from 20 to 16 airguns (or sometimes to 17 or 18). However, most of the turns between lines occurred at night, while the airguns were not operating. Reduction of the operating part of the airgun array has been a mitigation requirement of past IHAs issued to L-DEO. Although this reduction was not required for the current cruise, it was nonetheless implemented as a standard procedure. Operation of the airguns during turns allowed the subsequent resumption of geophysical data collection without needing to implement the 30-min observation and ramp-up requirements of the IHA (see Chapter 3 and Appendix A).

Other Types of Airgun Operations

Airguns operated during certain other periods besides periods with production seismic operations and line changes during the Chicxulub cruise. Airguns were operated during ramp ups, power downs, periods of equipment repair, and testing of the airguns. Ramp ups were required by the IHA (see Chapter

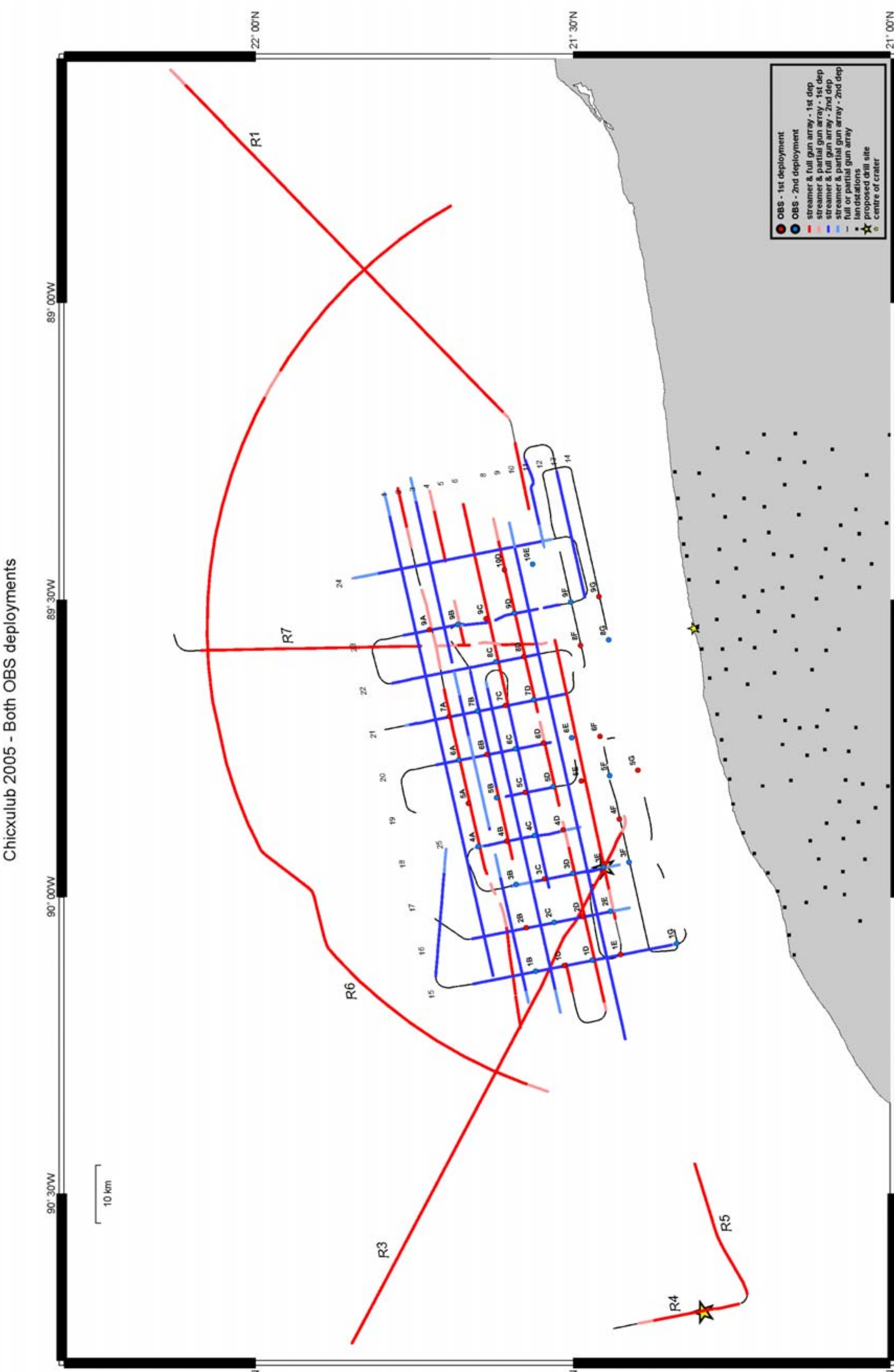

FIGURE 2.1. The Chicxulub seismic study area, *Ewing* ship tracks, and locations of seismic survey lines and OBSs during L-DEO's seismic survey off the northern Yucatán Peninsula, Gulf of Mexico, 7 Jan. – 20 Feb. 2005.

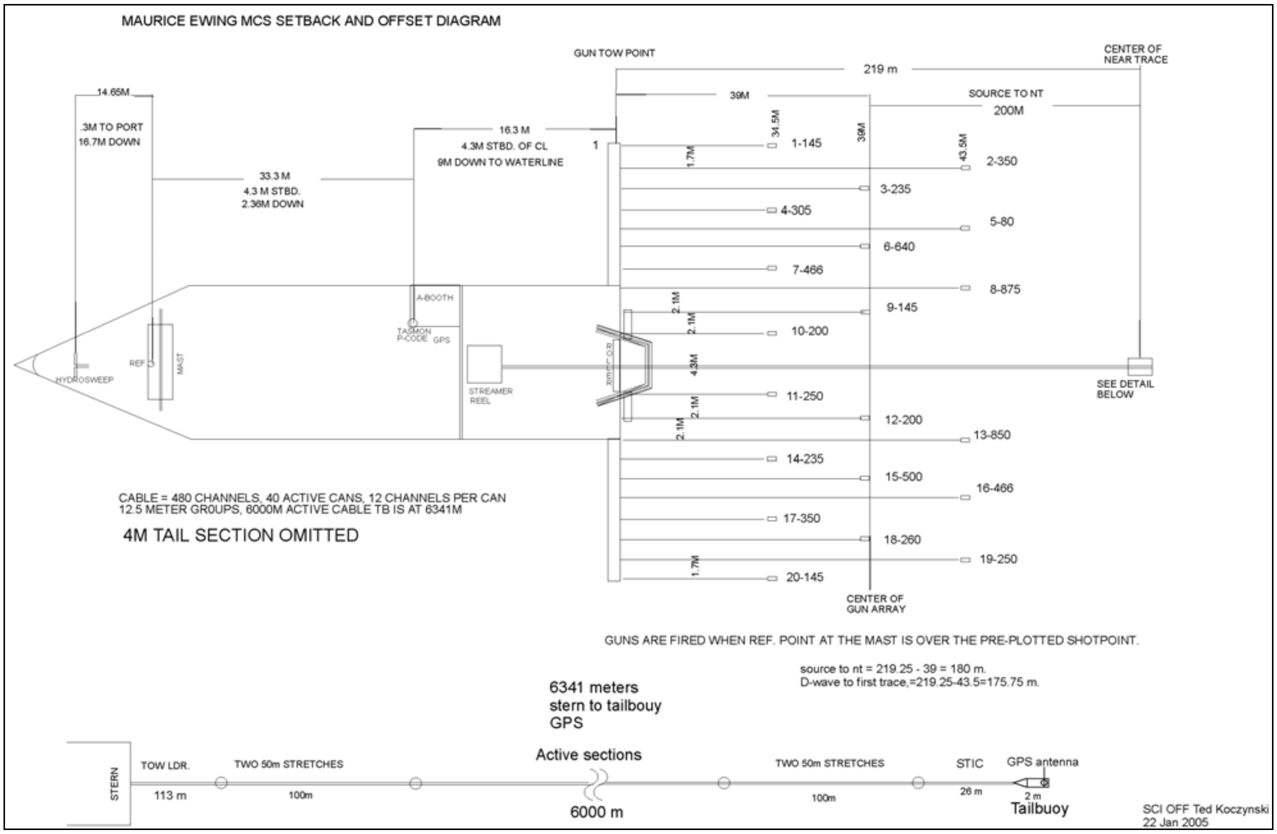

FIGURE 2.2. The configuration, setback, and offset of the 20-airgun array used during L-DEO's Chicxulub seismic survey off the northern Yucatán Peninsula, Gulf of Mexico, 7 Jan.–20 Feb. 2005. The volume (in^3) of each individual airgun is shown, e.g., 1-145 means "airgun no. 1, volume 145 in^3".

TABLE 2.2. Specifications of the 20-airgun array used during L-DEO's Chicxulub seismic study, 7 Jan.–20 Feb. 2005.

Energy source	Twenty 2000 psi Bolt airguns of 80–875 in^3
Source output (downward) [a]	253.5 dB re 1 μPa·m, 0-pk
Towing depth of energy source	7.0 m
Total air discharge volume	6970 in^3
Dominant frequency components	0–188 Hz

[a] Source level estimates are based on a filter bandwidth of ~0–250 Hz

3 and Appendix A). Ramp ups involved a systematic increase in the number of airguns firing; airguns were added every 5 min, to ensure that the source level of the array increased in steps not exceeding 6 dB per 5-min period. Ramp ups occurred when operations with the 20-airgun array commenced after a period without airgun operations, and after periods when only one airgun had been firing (e.g., after a power down for a marine mammal or sea turtle). Ramp ups of the airguns occurred on 56 occasions during the seismic study: 16 occurred after a single airgun had been operating for an extended period, and the remaining 40 involved a start up from no airguns operating.

Ocean Bottom Seismometers

At the beginning of the survey, 15-17 Jan. 2005, a total of 23 OBSs were deployed by the *Ewing* in the study area (Fig. 2.1). The seismic lines were then shot. From 2-4 Feb. 2005, the 23 OBSs were recovered and 25 OBSs were deployed in slightly different locations. The same seismic lines were then surveyed a second time.

Multibeam Bathymetric Sonar, Sub-bottom Profiler, and Fathometer

Along with the airgun operations, four additional acoustic systems operated during the cruise. A 15.5-kHz Hydrosweep MBB sonar and a 3.5-kHz sub-bottom profiler operated throughout most of the cruise to map the bathymetry and sub-bottom conditions, as necessary to meet the geophysical science objectives. During seismic operations, these sources typically operated simultaneously with the airgun array. A standard depth sounding sonar (i.e., fathometer or echosounder) was used occasionally for safety purposes when the *Ewing* was operating in shallow areas where the water depths were not well charted and near ports. This type of sonar is routinely employed by sea-going vessels to monitor water depths. The various sonars are described in further detail in Appendix C.

3. MONITORING AND MITIGATION METHODS

This chapter describes the marine mammal and sea turtle monitoring and mitigation measures implemented for L-DEO's Chicxulub seismic study, addressing the requirements specified in the IHA (Appendix A) as well as in documents from the Mexican government, in particular SEMARNAT. The section begins with a brief summary of the monitoring tasks relevant to mitigation for marine mammals and sea turtles. The acoustic measurements and modeling results used to identify the safety radii for marine mammals and turtles are then described. A summary of the mitigation measures required by NMFS and the extra mitigation measures that were set forth by SEMARNAT is then presented. The section ends with a description of the monitoring methods implemented for this cruise from aboard the *Ewing*, and a description of data analysis methods.

Monitoring Tasks

The main purposes of the vessel-based monitoring program were to ensure that the provisions of the IHA issued to L-DEO by NMFS were satisfied, effects on marine mammals and sea turtles were minimized, and residual effects on animals were documented. The objectives of the monitoring program were listed in Chapter 1, *Mitigation and Monitoring Objectives*. Tasks specific to monitoring are listed below (also see Appendix A):

- Provide qualified MMOs for the *Ewing* source vessel throughout the Chicxulub seismic survey.
- Visually monitor the occurrence and behavior of marine mammals and sea turtles near the airgun array whether the airguns were operating or not.
- Record (insofar as possible) the effects of the airgun operations and the resulting sounds on marine mammals and turtles.
- Use PAM to detect calling marine mammals whenever water depths permit, and notify visual observers of nearby marine mammals.
- Use the monitoring data as a basis for implementing the required mitigation measures.
- Estimate the number of marine mammals potentially exposed to airgun sounds.

Safety and Potential Disturbance Radii

Under current NMFS guidelines (e.g., NMFS 2000), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which the received pulse levels are ≥180 dB re 1 μPa (rms) for cetaceans and ≥190 dB re 1 μPa (rms) for pinnipeds. These safety criteria are based on an assumption that seismic pulses received at lower received levels are unlikely to injure these animals or impair their hearing abilities, but that higher received levels *might* have some such effects. Marine mammals exposed to ≥160 dB (rms) are assumed by NMFS to be potentially subject to behavioral disturbance. However, for certain groups (dolphins, pinnipeds), this is unlikely to occur unless received levels are higher, perhaps ≥170 dB rms for an average animal (see Chapter 1).

Radii within which received levels were expected to diminish to the various values (i.e., 190, 180, 170 and 160 dB re 1 μPa rms) were estimated by L-DEO (Table 3.1). This was done based on a combination of acoustic modeling, as summarized in LGL Ltd. (2003a,b), and empirical measurements of sounds from several airgun configurations involving 2–20 airguns (Tolstoy et al. 2004a,b). The results from the empirical study were limited in various ways. However, the empirical data did show that water depth

TABLE 3.1. Estimated distances to which sound levels ≥190, 180, 170 and 160 dB re 1 μPa (rms) might be received from the standard 8600 in^3 20-airgun array and from the one airgun used during power-downs, Chicxulub seismic survey, Jan.–Feb. 2005. Distance estimates are given for operations in shallow water (<100 m) where all seismic operations occurred. Safety radii implemented during the study are shown in boldface.[a]

Number of airguns	Volume (in^3)	Predicted RMS Distances (m)			
		190 dB	180 dB	170 dB	160 dB
20	8600	2000	**3500**	7000	12000
1	80	39	**108**	330	1050

[a] The safety radius for cetaceans and sea turtles is based on the 180-dB distance for the 20-airgun array with volume 8600 in^3. However, the total volume of the actual 20-airgun array used during the study (6970 in^3) was smaller.

affected the distance at which received level would exceed any specific level such as 180 or 170 dB re 1 μPa (rms). Therefore, L-DEO recognizes three strata of water depth for seismic cruises: deep (>1000 m), intermediate (100–1000 m), and shallow (<100 m), as well as the associated differences in 160–190 dB radii (see Smultea et al. 2004, 2005; Holst et al. 2005; MacLean and Koski 2005). However, all Chicxulub seismic survey operations were in water <~40 m deep, so only shallow water radii were used.

The 160–190 dB radii for this study were estimated assuming use of a 20-airgun array with a larger total discharge volume (8600 in^3) as compared with the actual volume (6970 in^3) used during the Chicxulub study. Thus, the "160–190 dB" radii applied in this study (Table 3.1) were somewhat precautionary (i.e., overestimated). However, the overestimation was slight given that sound pressure is more directly related to number of operating airguns than to total discharge volume (Caldwell and Dragoset 2000). Background on the results of the acoustic calibration study and sound modeling, in relation to these depth strata, is provided in Appendix B.

There were times when <20 airguns were firing (e.g., during turns between lines). At these times, the full safety radius for the 20-airgun array was assumed to apply, regardless of the number of airguns firing. The one exception was any period when there was a power down to one operating airgun.

Mitigation Measures as Implemented

The primary mitigation measures that were implemented during the Chicxulub cruise included ramp up, power down, and shut down of the airguns. These three measures are standard procedures employed during L-DEO seismic cruises and are described in detail in Appendix D. Mitigation also included those measures specifically identified in the IHA (Appendix A) and in the documents from SEMARNAT as indicated below. For the second time during an L-DEO seismic study, nighttime seismic operations were not permitted, as required by SEMARNAT. The first time that nighttime seismic operations were restricted during an L-DEO seismic survey by an IHA was during the calibration study of the *Ewing*'s airguns in the northern Gulf of Mexico in 2003 (Smultea et al. 2003).

Standard Mitigation Measures

Standard mitigation measures implemented during the study included the following:

1. The 20-airgun array had a lower total discharge volume than originally planned (6970 vs. 8600 in^3). Thus, the sound level produced by the airguns, and the exposure of marine mammals and sea turtles to airgun sounds, were slightly reduced.
2. The configuration of the array directed more sound energy downward, and to some extent fore and aft, than to the side of the track. This reduced the exposure of marine animals, especially to the side of the track, to airgun sounds.
3. Safety radii implemented for the Chicxulub cruise were specific for shallow water and based on the acoustic calibration study conducted from the *Ewing* in the Gulf of Mexico in 2003 (Tolstoy et al. 2004a,b), as discussed earlier in this chapter and in Appendix B.
4. Power-down or shut-down procedures were implemented when a marine mammal or turtle was sighted within or near the applicable safety radius while the airguns were operating.
5. A change in vessel course and/or speed alteration was identified as a potential mitigation measure if a marine mammal was detected outside the safety radius and, based on its position and motion relative to the ship track, was judged likely to enter the safety radius. However, substantial alteration of vessel course or speed was not feasible during the Chicxulub cruise given the length (6 km) of the streamer being towed. Power downs or shut downs were the preferred and most practical mitigation measures when mammals or turtles were sighted within or about to enter the safety radii.
6. Ramp-up procedures were implemented whenever the 20-airgun array was powered up, to gradually increase the size of the operating source at a rate no greater than 6 dB per 5 min, the maximum ramp-up rate authorized by NMFS in the IHA and during past L-DEO seismic cruises.
7. Ramp up could not proceed if marine mammals or sea turtles were known to be within the safety radius, or if there had been visual detection(s) inside the safety zone within the following periods: 30 min for mysticetes, sperm whales, and beaked whales; ~25 min for turtles; and 15 min for small odontocetes. (The period for sea turtles was based on the amount of time it would take the vessel to leave the turtle behind and outside of the safety radius).
8. The airgun array was reduced from 20 airguns to 16–18 airguns during vessel turns (line changes). This reduction in airguns was a requirement during past cruises (e.g., Holst et al. 2005; Smultea et al. 2005) although not specifically during this cruise.

Special Mitigation Measures for the Chicxulub Cruise as required by SEMARNAT

9. No seismic operations were conducted at night, or between 18:00 and 06:30 local Central Standard Time (CST). Because of the necessary 30 min observation period before ramp up, and the poor lighting conditions until 06:15, ramp up was typically not started until ~06:45.
10. No seismic operations were allowed during Beaufort Wind Force (Bf) >4 (i.e., wind speed >16 kt). This requirement was amended during the cruise from the initial requirement, which did not allow operations in Bf >2, the latter limitation being impractical.
11. PAM was conducted from 1 h before ramp up until full darkness where water depths were great enough to make PAM possible. (The PAM system was typically monitored until 18:30 CST.)
12. Three Mexican observers were required to be onboard at all times when seismic was being conducted.
13. Seismic operations were suspended if fishermen were seen within 1500 m of the *Ewing*.
14. A small boat (spotter vessel) was used during most times while the *Ewing* was operating the airguns to (***A***) alert vessels in the path of the survey, and (***B***) observe the potential impact of seismic

operations on marine organisms. (No marine mammals or turtles, dead or alive, were sighted from this watch boat.)

15. Aerial overflights were conducted before, during, and after the seismic survey.

Visual Monitoring Methods

Visual monitoring methods were designed to meet the requirements identified in the IHA (see above and Appendix A) and by SEMARNAT. The primary purposes of MMOs aboard the *Ewing* were as follows: ***(1)*** Conduct monitoring and implement mitigation measures to avoid or minimize exposure of marine mammals and sea turtles to airgun sounds with received levels >180 dB re μPa (rms). ***(2)*** Document numbers of marine mammals and sea turtles present and any reactions to seismic activities. The data collected were used to estimate the number of marine mammals potentially affected by the project. Results of the monitoring effort are presented in Chapters 4 and 5.

The visual monitoring methods that were implemented during this cruise were very similar to those during previous L-DEO seismic cruises. In chronological order, those were described by Smultea and Holst (2003), Smultea et al. (2003), MacLean and Haley (2004), Holst (2004), Smultea et al. (2004), Haley and Koski (2004), MacLean and Koski (2005), Smultea et al. (2005), and Holst et al. (2005). The standard visual observation methods are described in Appendix D

In summary, during the Chicxulub survey, at least one MMO maintained a visual watch for marine mammals and sea turtles during all daylight hours from dawn to dusk. During this cruise, two visual observers were on duty for 90 % of the time when visual watches were underway. Visual observations were conducted from the *Ewing*'s flying bridge or (during inclement weather) from the bridge. Because of the restrictions from SEMARNAT, no nighttime seismic operations were conducted, and nighttime visual watches were unnecessary. Observers focused search effort forward of the vessel but also searched aft of the vessel while it was underway. Watches were conducted with the naked eye, Fujinon 7 × 50 reticle binoculars, and mounted 25 × 150 Big-eye binoculars. Appendix D provides further details regarding visual monitoring methods.

Passive Acoustic Monitoring Methods

To complement the visual monitoring program, passive acoustic monitoring was conducted as required by the IHA (Appendix A) and by SEMARNAT. A requirement for PAM was first specified by IHAs issued to L-DEO during early 2004 for the present cruise (Appendix A; NMFS 2004) and for a *Ewing* seismic cruise in the Southeast Caribbean (Smultea et al. 2004). PAM was again required and conducted for L-DEO's Blanco seismic cruise in pelagic waters off Oregon in autumn 2004 (Smultea et al. 2005) and during a seismic cruise in the Eastern Tropical Pacific off Central America (ETPCA; Holst et al. 2005). Visual monitoring typically is not effective during periods of bad weather or at night, and even with good visibility, is unable to detect marine mammals when they are below the surface or beyond visual range. Acoustical observations can be used in addition to visual observations to improve detection, identification, localization, and tracking of cetaceans.

In practice, acoustic monitoring served to alert visual observers when vocalizing cetaceans were in the area. The SEAMAP (Houston, TX) PAM system aboard the *Ewing* often detects calling cetaceans before they are seen by visual observers or when they are not sighted by visual observers (Smultea et al. 2004, 2005; Holst et al. 2005). This helps to ensure that cetaceans are not nearby when seismic operations are underway or about to commence. During this cruise, the acoustical system was monitored in real time so that the visual observers could be advised when cetaceans were heard, as directed in the IHA.

This approach had been implemented successfully aboard the *Ewing* during L-DEO's aforementioned 2004 SE Caribbean, Blanco, and ETPCA seismic cruises.

The SEAMAP system was the primary acoustic monitoring system used during this and earlier seismic surveys (see Appendix D for a description of this system). The lead-in from the hydrophone array was ~300 m long, and the active part of the hydrophone array was 56 m long. During the Chicxulub survey, the hydrophone array was towed at variable depths due to shallow water in the study area. Also, because of problems with the SEAMAP software during the preceding ETPCA cruise, acoustic monitoring software developed by CIBRA (University of Pavia, Italy) was used to record cetacean calls detected by the SEAMAP hydrophones (see Appendix D).

While at the seismic survey area, the hydrophone array was monitored from 05:45 CST (1 h before ramp up) until total darkness (18:30 CST) during periods with airgun operations and during most periods when airguns were off. PAM was only conducted during darkness during the first few nights of the seismic survey, as the number of PAM personnel was limited, and no acoustic detections were made during the day or night until 28 Jan. While the *Ewing* was in the seismic survey area, the SEAMAP array was typically used to complement daytime visual monitoring, whether airguns were operational or not.

One MMO monitored the acoustic detection system by listening to the signals from two channels via headphones and/or speakers, and watching the map-based database viewer on two computer monitors for frequency ranges produced by cetaceans. MMOs monitoring the acoustical data were usually on shift for 1–2 h. All MMOs rotated through the PAM position, although the most experienced with acoustics was on PAM duty more frequently.

When cetacean calls were heard, the visual observers on the flying bridge or bridge were immediately notified of the presence of calling marine mammals. Each acoustic "encounter" was assigned a chronological identification number. An acoustic encounter was defined as including all calls of a particular species or species-group separated by <1 h (Manghi et al. 1999).

Analyses

Categorization of Data

Visual and acoustic effort, as well as marine mammal sightings and acoustic detections, were divided into several analysis categories related to vessel and seismic activity. The categories used were similar to those used during recent L-DEO seismic studies (e.g., Haley and Koski 2004; MacLean and Koski 2005; Smultea et al. 2005; Holst et al. 2005). These categories are defined briefly below, with a more detailed description provided in Appendix D

In general, data were categorized as "seismic" or "non-seismic". "Seismic" included all data collected while the airguns were operating, including ramp ups, and periods up to 90 s after the airguns were shut off. Non-seismic includes all data obtained before airguns were turned on (pre-seismic) or >6 h after the airguns were turned off. Data collected during post-seismic periods from 1.5 min to 6 h after cessation of seismic were considered either "recently exposed" (90 s–2 h) or "potentially exposed" (2–6 h) to seismic, and were excluded from analyses. Thus, they were not included in either the "seismic" or "non-seismic" categories. The 6-h post-seismic cut-off is the same cut-off used during the SE Caribbean and Blanco seismic cruises when moderate or large (10–20 airgun) arrays were also used. A shorter (i.e., 2-h) post-seismic cut off was used during other recent cruises where the safety radii were considerably smaller because the seismic sources were much smaller (Haley and Koski 2004; MacLean and Koski 2005; Holst et al. 2005).

This categorization system was designed primarily to distinguish situations with ongoing seismic surveys from those where any seismic surveys were sufficiently far in the past that it can be assumed that they had no effect on current behavior and distribution of animals. The rate of recovery toward "normal" during the post-seismic period is uncertain. Therefore, the post-seismic period was defined so as to be sufficiently long (6 h) to ensure that any carry-over effects of exposure to the sounds from the large 20-airgun array surely would have waned to zero or near-zero. The reasoning behind these categories was explained in MacLean and Koski (2005) and Smultea et al. (2005) and is discussed in Appendix D

Line Transect Estimation of Densities

Marine mammal sightings during the "seismic" and "non-seismic" periods were used to calculate sighting rates (#/km). Sighting rates were then used to calculate the corresponding densities (#/km^2) of marine mammals near the survey ship during seismic and non-seismic periods. Density calculations were based on line transect principles (Buckland et al. 2001). Because of assumptions associated with line-transect surveys [sightability, $f(0)$, $g(0)$, etc.], only "useable" effort and sightings were included in density calculations. Effort and sightings were defined as "useable" when made under the following conditions: daylight periods both within the seismic survey area and during transit to and from that area, ***excluding*** periods 90 s to 6 h after airguns were turned off (post-seismic), or when ship speed <3.7 km/h (2 kt), or with seriously impaired sightability. The latter included all nighttime observations, and daytime periods with one or more of the following: visibility <3.5 km, Bf >5, or >60º of severe glare between 90º left and 90º right of the bow.

Correction factors for missed animals, i.e., $f(0)$ and $g(0)$, were taken from other related studies, as summarized by Koski et al. (1998) and Mullin and Hoggard (2000). This was necessary because of the low number of sightings of any individual species, and the inability to assess trackline sighting probability, during a study of this type.

Densities during non-seismic periods were used to estimate the numbers of animals that presumably would have been present in the absence of seismic activities. Densities during seismic periods were used to estimate the numbers of animals present near the seismic operation and exposed to various sound levels. The difference between the two estimates could be taken as an estimate of the number of animals that moved in response to the operating seismic vessel, or that changed their behavior sufficiently to affect their detectability to visual observers. Further details on the line transect methodology used during the survey are provided in Appendix D

Analyses of marine mammal behavior in "seismic" vs. "non-seismic" conditions were also limited to "useable" sightings and effort.

Estimating Numbers Potentially Affected

For purposes of the IHA, NMFS assumes that any marine mammal that might have been exposed to airgun pulses with received sound levels ≥160 dB re 1 μPa (rms) may have been disturbed. When calculating the number of mammals potentially affected, the nominal 160 dB radii for the number of airguns then in use were applied (Table 3.1). Most commonly, the source consisted of 20 airguns, as discussed in Chapter 2. Of 1892 km of transect with airguns operating, 20 airguns were operating for 1497 km, with fewer airguns operating for 395 km. The distances in Table 3.1 are probably somewhat overestimated and precautionary, particularly given that the radii for the larger-volume (8600 in^3) 20-airgun array were used for these calculations, in place of radii specific to the smaller-volume (6970 in^3) 20-airgun array actually employed during the Chicxulub study.

Two approaches were applied to estimate the numbers of marine mammals that may have been exposed to sound levels ≥160 dB re 1 μPa (rms):

1. Estimates of the numbers of potential *exposures* of marine mammals, and
2. Estimates of the number of different *individual* mammals exposed (one or more times).

The first method ("exposures") was obtained by multiplying the following three values for each airgun configuration in use: ***(A)*** km of seismic survey; ***(B)*** width of area assumed to be ensonified to ≥160 dB (2 × 160 dB radius); and ***(C)*** "corrected" densities of marine mammals estimated by line transect methods.

The second approach ("individuals") involved multiplying the corrected density of marine mammals by the area exposed to ≥160 dB one or more times during the course of the study. In this method, areas ensonified to ≥160 dB on more than one occasion, e.g., when seismic lines crossed, were counted only once.

The two approaches can be interpreted as providing minimum and maximum estimates of the number of marine mammals exposed to sound levels ≥160 dB re 1 μPa (rms). The actual number exposed is probably somewhere between these two estimates. This approach was originally developed to estimate numbers of seals potentially affected by seismic surveys (Harris et al. 2001), and has recently been used in various L-DEO reports to NMFS (e.g., Haley and Koski 2004; Smultea et al. 2004, 2005; MacLean and Koski 2005; Holst et al. 2005). The methodology is described in detail in these past reports and in Appendix D

4. MARINE MAMMALS

Introduction

This chapter provides background information on the occurrence of marine mammals in the project area, and describes the results of the marine mammal monitoring program. In addition, the number of marine mammals potentially affected during project operations is estimated. Results of the sea turtle monitoring program are presented in Chapter 5. Preliminary results of the geophysical studies conducted aboard the *Ewing* during this project are summarized in Gulick (2005a,b).

Seismic operations were conducted along 1892 km of trackline over a total of 205 h (Fig. 4.1; Table ES.1). In total, 4281 km of visual observations and 2935 km of PAM were conducted within the study area, including applicable effort during transit. "Useable" survey conditions, including daylight effort within and during transit to and from the seismic survey area, occurred during 83% of the total visual effort (Fig. 4.2). "Useable" effort excluded periods 90 s to 6 h after airguns were turned off, poor visibility conditions (visibility <3.5 km or extensive glare), Bf >5, and *Ewing* ship speed <3.7 km/h (2 kt). The project provided data on the winter occurrence, distribution, and abundance of cetaceans in shallow waters (<100 m) off the northern Yucatán Peninsula in the southern Gulf of Mexico, an area where few survey data had been collected previously.

The marine mammals that occur in the Gulf of Mexico belong to thee taxonomic groups: the odontocetes (toothed cetaceans, such as dolphins), mysticetes (baleen whales), and sirenians (the West Indian manatee). No species of pinnipeds are known to occur regularly in this region. The Chicxulub seismic operations occurred in shallow water (<100 m). Only 2 of the total 29 marine mammal species known to occur in the Gulf of Mexico occur regularly in the shallow coastal waters of the project area: the bottlenose dolphin and the Atlantic spotted dolphin (Jefferson and Schiro 1997; Würsig et al. 2000; Appendix E.1). Neither of these delphinid species is listed as Threatened or Endangered under the U.S. ESA. Unlike the situation in the northern Gulf of Mexico, little is known about cetacean abundance and distribution in the southern Gulf, particularly the Chicxulub study area; only opportunistic sightings and strandings have been reported previously (Jefferson and Lynn 1994; Jefferson and Schiro 1997; Würsig et al. 2000; Ortega-Ortiz 2002). Appendix E.1 summarizes the abundance, habitat, and conservation status of the 29 cetacean species known to occur in the entire Gulf of Mexico.

Monitoring Effort and Cetacean Encounter Results

This section summarizes the visual and acoustic monitoring effort and resulting sightings/detections from the *Ewing* during the Chicxulub seismic cruise from 7 Jan.–20 Feb. 2005. The study area is shown in Fig. 4.1 and is defined in Chapter 3. The data categories and definitions used for analyses were discussed in Chapter 3. Summaries of results of visual and acoustic monitoring are presented here, with detailed data summaries presented in Appendix F, including survey effort in both kilometers and hours. A general summary of effort and sightings is shown in Table ES.1. Additional spotter vessel and aerial survey effort conducted by L-DEO, as required by SEMARNAT (see Chapter 3), is also summarized.

Visual Survey Effort from Ewing

All *Ewing* survey tracks are plotted by seismic activity (airguns on or off) in Figure 4.1 and by visual survey effort (useable, non-useable, none) in Figure 4.2. During 9476 km of *Ewing* operations during the cruise, 3562 km of useable visual observations were made (Table ES.1). This total excludes 422 km of effort while in transit from Panama to the study area. That part of the transit was through the

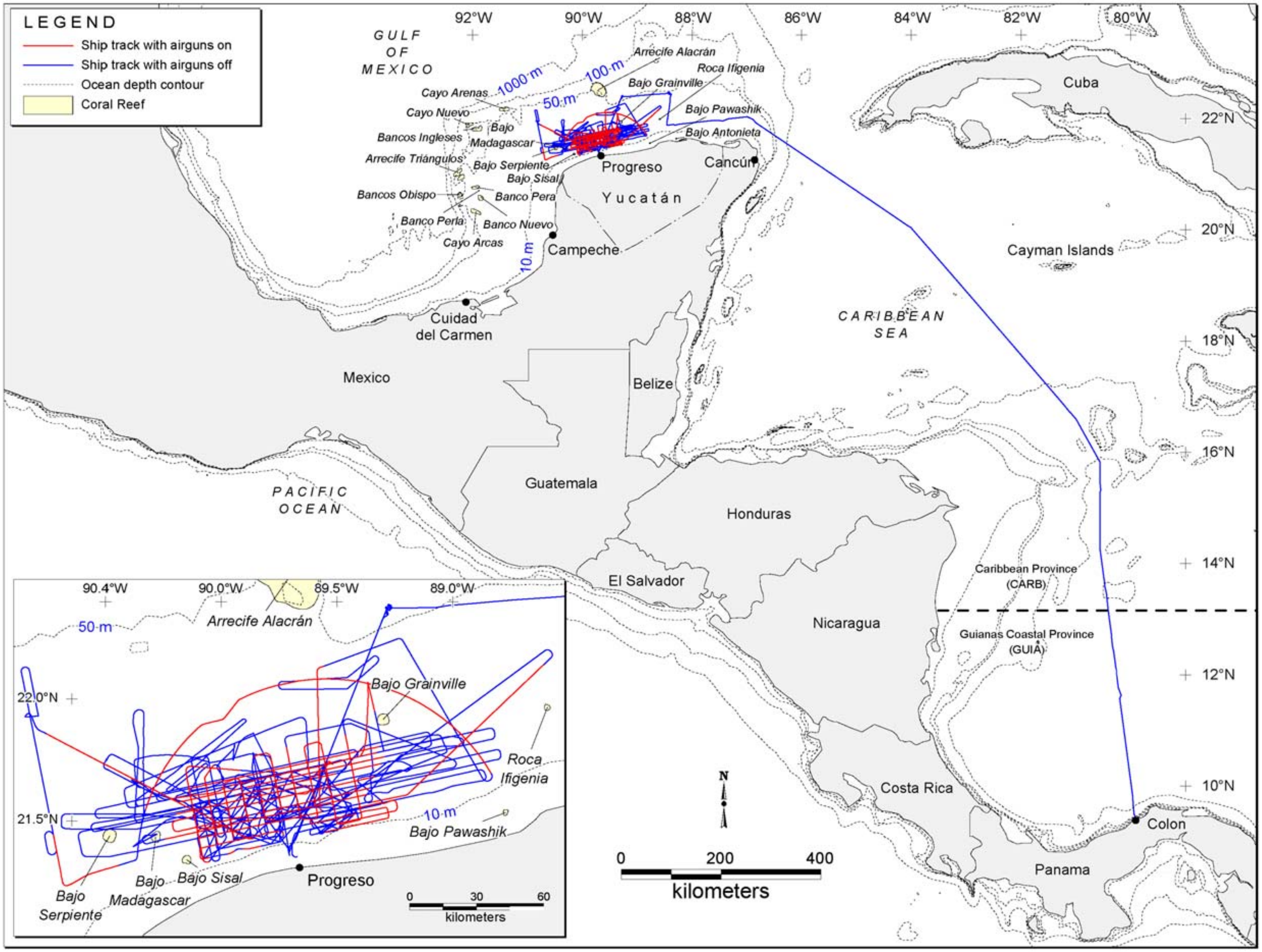

FIGURE 4.1. *Ewing* survey tracks showing airguns on and off during the Chicxulub seismic study in the southern Gulf of Mexico, Jan.–Feb. 2005.

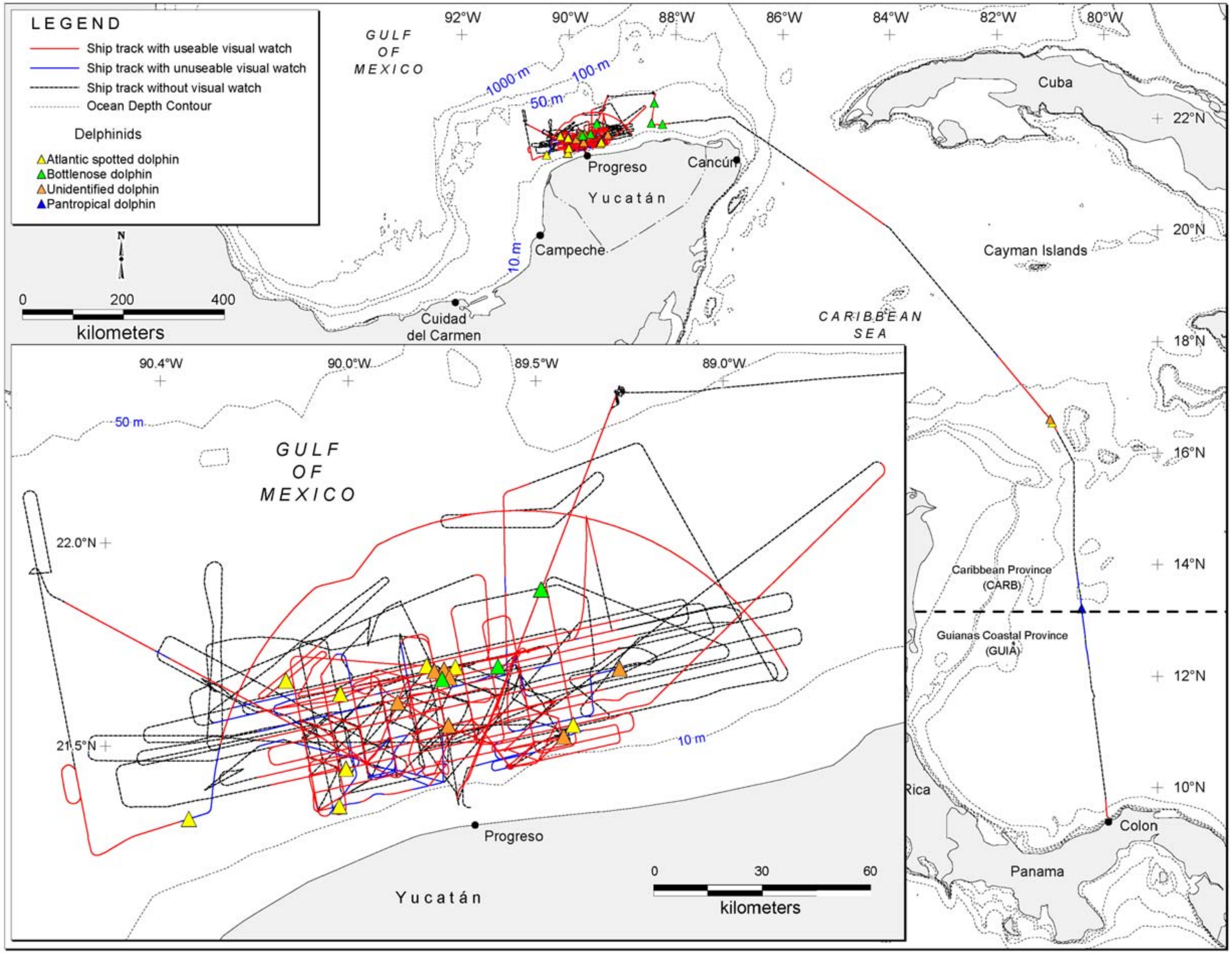

FIGURE 4.2. *Ewing* survey tracks with and without visual effort, and marine mammal sightings, during the Chicxulub seismic study in the southern Gulf of Mexico, Jan.–Feb. 2005.

Caribbean Ecological Province (Longhurst 1998), and there were no seismic operations or marine mammal or sea turtle sightings there. Useable survey effort, subdivided by airguns on or off and water depth strata, is shown in Appendix F.1. MMOs observed during all daylight seismic periods. No visual effort occurred at night. Two MMOs were on watch during 90% of all visual watches, and one MMO was on watch during the remaining 10%. MMOs observed primarily (99% of all watches) from the flying bridge, with the remaining watches conducted from the bridge.

Beaufort Wind Force during observations ranged from 1 to 6, with 95% of the observations in conditions of Bf ≤5 (i.e., useable). About one-third (35%) of the useable observation effort (Bf 1 to 5) occurred during Bf ≤3 (wind speed 0.0–5.1 m/s); the remaining 65% occurred during Bf 4 or 5 (Appendix F.2).

Visual Sightings of Marine Mammals and Other Vessels

Numbers of Marine Mammals Seen.—An estimated ~119 individual cetaceans were seen in 24 groups during the study period; 18 were seen in the seismic survey area and 6 during transit to the study area (Fig. 4.2; Appendices F.3, F.4). The only cetacean species identified were bottlenose, Atlantic spotted, and pantropical spotted dolphins (Tables 4.1, 4.2). In terms of individuals, Atlantic spotted dolphins were the most abundant (n = 36), followed by bottlenose dolphins (n = 32; Table 4.1). Two calves and one juvenile Atlantic spotted dolphin were seen among the 119 individual delphinids observed. Only one group of 10 pantropical spotted dolphins was sighted; this group was seen during the transit from Panama in deep (>1000 m) water (Fig. 4.2) during a period with Bf 6. An additional two sightings of dolphins were made during transit in intermediate-depth waters (100–1000 m), and three in-transit sightings were made in shallow water (<100 m). The remaining 18 sightings were made in the seismic operations area in shallow water (<100 m) where most of the effort occurred (Fig. 4.2; Appendix F.1). A detailed list of sightings is provided in Appendix F.3.

Most of the 24 sightings (79% or 19 groups) made within the study area, including transits, were "useable" (Tables 4.1, 4.2). These "useable" sightings, along with the corresponding effort data, are the basis for the ensuing analyses comparing sighting rates, behaviors, and densities of marine mammals during seismic and non-seismic periods.

Sightings with Airguns On.—Of the total 24 sightings, 7 were made while the airguns were on, 14 were made during non-seismic periods, and the remaining 3 were noted during "post-seismic" periods (i.e., "non-useable"; Tables ES.1 and 4.1; Appendix F.4). Four of the seven groups sighted during seismic were seen while 20 airguns were operating, two groups were seen while one airgun was firing, and the remaining group was seen during a ramp up.

The airguns were shut down once and powered down four times because of the presence of presumably different individual cetaceans within or near the designated safety zone. Further details on these encounters are provided later in this chapter (see *Cetaceans Potentially Exposed to Sounds ≥180 dB*) and in Appendix G. There were seven additional power downs and shut downs for sea turtles (see Chapter 5)

Sighting/Detection Rates.—Sighting rates (# groups sighted per unit effort) during various types of MMO effort are presented in Table 4.3. Based on the number of groups seen per kilometer, the sighting rate was about twice as high during non-seismic as during seismic conditions (Table 4.3). These rates are based on similar amounts of visual effort (Table ES.1; Fig. 4.2). Densities (#/km^2) and acoustic detection rates were also higher during non-seismic vs. seismic periods as discussed later in this chapter (Table 4.3).

TABLE 4.1. Number of sightings and individual cetaceans, both ***(A)*** total and ***(B)*** useable[a], observed from the *Ewing* in the study area during the Chicxulub seismic cruise, 7 Jan.–20 Feb. 2005. No pinnipeds, sirenians, or whales were sighted. Includes the portion of the transit to the study area that was within the "Caribbean Province" of Longhurst (1998) (see Fig. 4.2).

	Seismic		Post-Seismic		Non-seismic		Total	
	Groups	Indiv.	Groups	Indiv.	Groups	Indiv.	Groups	Indiv.
A. All Sightings								
Odontocetes								
Delphinids								
Bottlenose dolphin	2	6	2	15	4	26	6	32
Atlantic spotted dolphin	2	4	0	0	5	32	7	36
Pantropical spotted dolphin	0	0	0	0	1	10	1	10
Unidentified dolphin	3	3	1	0	4	22	7	25
Total Cetaceans	**7**	**13**	**3**	**15**	**14**	**90**	**24**	**119**
B. Useable Sightings								
Odontocetes								
Delphinids								
Bottlenose dolphin	2	6	N/A	N/A	4	26	6	32
Atlantic spotted dolphin	2	4	N/A	N/A	5	32	7	36
Pantropical spotted dolphin	0	0	N/A	N/A	0	0	0	0
Unidentified dolphin	2	2	N/A	N/A	4	22	6	24
Total "Useable" Cetaceans	**6**	**12**	**N/A**	**N/A**	**13**	**80**	**19**	**92**

Note: N/A means not applicable; useable sightings excluded sightings during post-seismic periods.
[a] Useable sightings are those made during useable daylight periods of visual observation, as defined in *List of Acronyms and Abbreviations*.

Daytime sighting rates were similar between "useable" visual effort and all effort (e.g., useable plus non-useable effort; Table 4.3). This is not unexpected given that most effort was useable (Table 4.3). Effort was too low to allow meaningful comparisons between sighting rates during useable vs. non-useable periods.

Other Vessels—The IHA required that MMOs record the number and characteristics of vessels <5 km from any marine mammal sightings (Appendix A). There were numerous vessels of various types near the *Ewing* throughout the study. The most common were small fishing boats, but several cruise ships, cargo vessels, a tanker, a container ship, and a sailboat were also seen. Most of these vessels were at distances >5 km from any cetaceans sighted by MMOs. In addition, a spotter vessel was <1 km ahead of the *Ewing* during most seismic operations and thus within 5 km of all dolphin sightings during seismic operations. However, no obvious reactions by the dolphins to that vessel were observed. On several occasions, the spotter vessel or a Mexican Navy vessel approached the *Ewing* for personnel transfers, etc. On two occasions, vessels other than the spotter vessel were seen <5 km from a cetacean; these are summarized below.

On 1 Feb. at 15:21 GMT, one unidentified dolphin was observed while the 20-airgun array was in operation. The dolphin was seen swimming parallel to the *Ewing* at a distance of ~1 km off the port side. The spotter vessel was ~1 km ahead of the *Ewing* at the time, and a fishing boat was located ~2.5 km from the dolphin on the starboard side of the *Ewing*. There was no obvious reaction by the dolphin to the *Ewing*, the spotter vessel, or the fishing boat.

TABLE 4.2. Number of visual and acoustic detections of cetacean groups from the *Ewing* during the Chicxulub cruise (including transits), 7 Jan.–20 Feb. 2005. Numbers in parentheses are numbers of individuals. For acoustic detections, group size was unknown except in cases with concurrent visually-matched sightings.

	Ewing Visual-Only Sightings (# Indiv.)		*Ewing* Acoustic-Only Detections	Matched *Ewing* Visual/Acoustic Detections (# Indiv.)		Total		
						Visual Sightings (# Indiv.)		All Acoustic Detections
Species	**All**	**Useable[a]**		**All**	**Useable[a]**	**All**	**Useable[a]**	
Bottlenose dolphin	6 (37)	5 (27)	-	2 (10)	1 (5)	8 (47)	6 (42)	2
Pantropical spotted dolphin	1(10)	0 (0)	-	-	-	1 (10)	0 (0)	-
Unidentified dolphin	7 (25)	5 (23)	10	1 (1)	1 (1)	8 (26)	6 (24)	11
Atlantic spotted dolphin	7 (36)	7 (36)	-	-	-	7 (36)	7 (36)	-
Total	**21 (108)**	**17 (86)**	**10**	**3 (11)**	**2 (6)**	**24 (119)**	**19 (92)**	**13**

[a] Useable detections are those made during (or, for acoustic detections, concurrent with) useable daylight visual observations; see *Acronyms and Abbreviations* for the definition of "useable" observation effort.

TABLE 4.3. Encounter rates for acoustic detections and visual sightings from the *Ewing* during the Chicxulub seismic survey, 7 Jan.–20 Feb. 2005.

	Non-seismic			Seismic			Total [c]		
Effort Type[b]	**No. of Detect.**	**Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Detect.**	**Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Detect.**	**Effort (km)**	**Detection Rate (No./1000 km)**
All Visual	14	1983	7.1	7	1892	3.7	21	3875	5.4
Useable[a] Visual	13	1707	7.6	6	1855	3.2	19	3562	5.3
Useable[a] PAM	4	435	9.2	5	1847	2.7	9	2282	3.9
All PAM	7	569	12.3	5	1884	2.7	12	2453	4.6
PAM Daylight Only	4	442	9.1	5	1884	2.7	9	2326	3.9
PAM Nighttime Only	3	127	23.6	0	-	-	3	127	23.6

[a] Useable detections are those made during (or, for acoustic detections, concurrent with) useable daylight visual observations as defined in *Acronyms and Abbreviations*.
[b] All visual effort was conducted during daylight, and nearly all PAM effort occurred during the day.
[c] The total detections and effort for **seismic+non-seismic** do not equal **total**, because of detections and effort in the **recently** and **potentially exposed** *(i.e., "Post-seismic")* categories that are not included in this table. Some other totals may not add up exactly, due to rounding.

On 2 Feb. at 19:15 GMT, a group of 10 bottlenose dolphins was seen after the airgun array had been shut down for a sea turtle. The dolphins were seen milling ~70 m from the bow of the *Ewing* for about 30 s. Four small fishing boats were located within 5 km of the animals: one was located 4 km straight ahead of the *Ewing*, one was 3 km off the port side of the *Ewing*, and another two were seen 4 km away at the 2 o'clock position (i.e., 60º to the right of the *Ewing*'s bow). There was no obvious reaction by the dolphins to any of these vessels.

Other L-DEO Survey Effort

Spotter Vessel.—As required by SEMARNAT, a local Mexican fishing vessel was hired by L-DEO to travel ~1 km ahead of the *Ewing* during seismic operations to alert fishing vessels to move away from the *Ewing*'s course, to avoid potential entanglements of the airgun array and 6-km-long streamer with fishing operations. The crew aboard this spotter vessel was also asked to record any opportunistic sightings of marine mammals or sea turtles. However, they reported no sightings. There was no specific MMO aboard this vessel.

Aerial Surveys.—Also as required by SEMARNAT, L-DEO chartered a small twin-engine Piper Apache aircraft to conduct aerial surveys before, during, and after seismic operations in the Chicxulub survey area. The purpose of the surveys was to search for organisms that may have been injured as a result of airgun operations. Each flight was conducted by a minimum of a pilot/observer and an observer. Surveys were typically conducted along the seismic survey line being shot the day of the survey, along line(s) shot the previous day, and as time permitted, along line(s) to be shot in the near future. Most of the coastal areas near the survey lines were also surveyed during each flight.

A total of 19 aerial surveys were conducted, spaced approximately every two days, from 12 Jan. though 19 Feb. 2005. A total of ~12,240 km and 58.5 h of aerial survey were conducted in the seismic operations area, excluding transits from Merida, Mexico, to the coast. No sea turtles were seen during aerial surveys. Two marine mammal sightings were made as follows: On 21 Jan., a group of three probable bottlenose dolphins was seen feeding on a large school of fish near a seismic survey line scheduled to be shot on subsequent days. On 12 Feb., a group of eight probable bottlenose dolphins was seen near the coast >15 km west-southwest of the nearest seismic line during the return transit to the airport. No stranded marine mammals or sea turtles were seen during the surveys. Survey results are described in further detail in a report submitted by L-DEO to the Mexican government (Rawson 2005).

Distribution of Cetaceans

Cetacean sightings in the study area are plotted in Figure 4.2. Acoustic detections of cetaceans are plotted in Figure 4.3 and are discussed in detail later. As noted earlier, no systematic vessel-based cetacean surveys had been conducted in the southern Gulf of Mexico prior to this survey, and little was known about cetaceans in the Chicxulub study region.

Observations and acoustic detections during the Chicxulub study confirmed that bottlenose and Atlantic spotted dolphins are the primary cetacean species in the seismic study area. This was expected given the known association of these species with shallow waters (<100 m) of the southern Gulf of Mexico. The 18 delphinid groups seen within the seismic survey area from the *Ewing* occurred in water depths of ~9–36 m; water depths with seismic operations were ~9–40 m (Fig. 4.2). Delphinids were generally seen throughout the seismic survey area wherever visual observations occurred, including before, during, and after the seismic operations (Fig. 4.2; Appendix F.3). A small concentration of 6 sightings (33% of the 18 sightings in the seismic area) occurred near 21º39'N and 89º45'W while no or one airgun was operating (see inset on Fig. 4.2; Appendix F.3). Some sightings may have been repeat sightings of the same cetaceans, given the close spacing of seismic lines (Fig. 4.1, 4.2), although none were confirmed to be resightings.

Marine Mammal Behavior

The data collected during visual observations provide information about behavioral responses of marine mammals to the seismic survey: estimated closest observed point of approach to the airguns (CPA), movement relative to the vessel/array, and observed behavior of animals that were sighted.

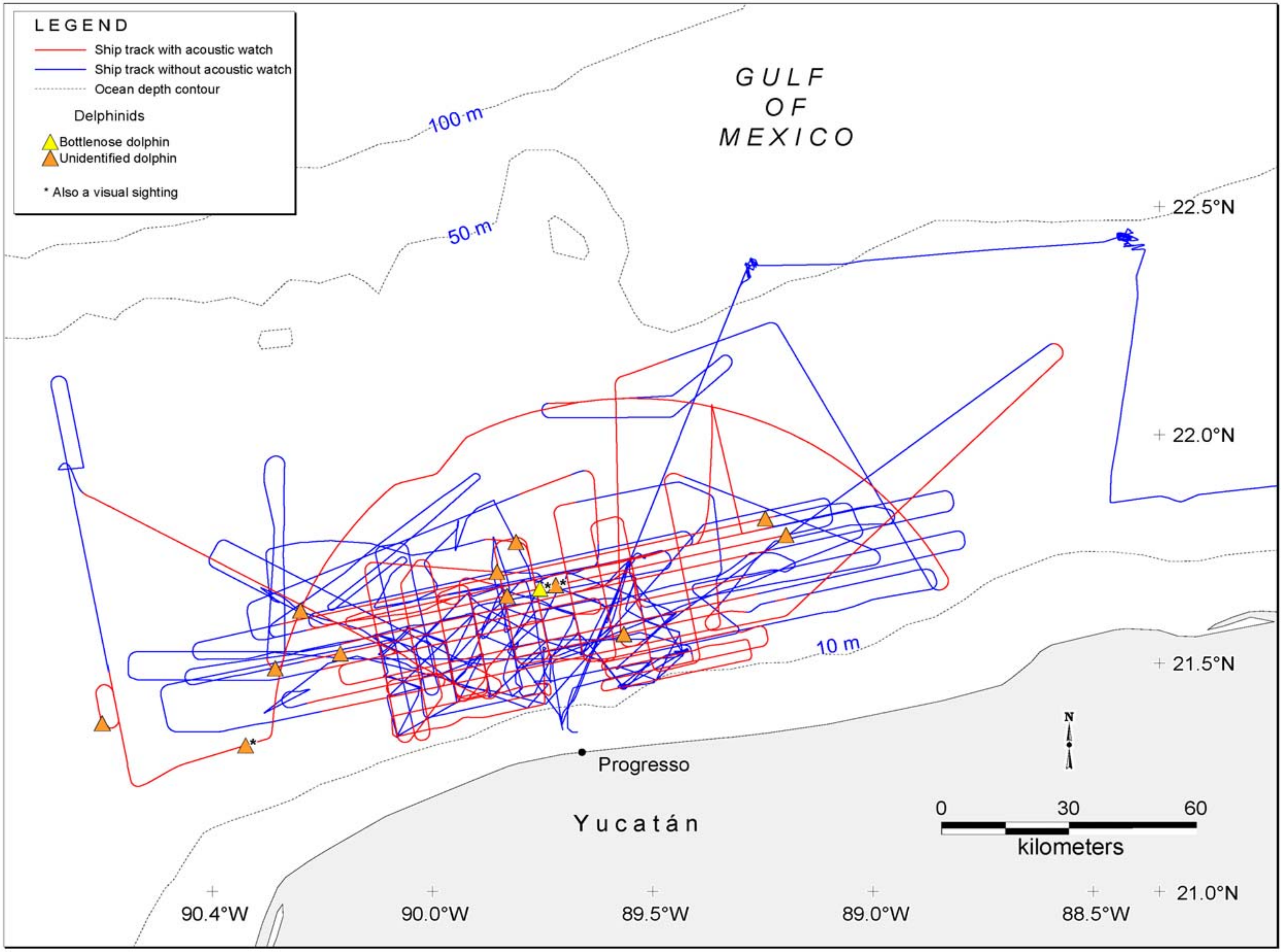

FIGURE 4.3. Locations of all cetacean acoustic detections during the Chicxulub survey, showing periods with and without acoustic monitoring effort, 7 Jan. – 20 Feb. 2005.

Closest Observed Point of Approach

Delphinids were seen closer to the airgun array when the airguns were off vs. on, considering only useable sightings (mean 178 vs. 472 m; n = 6 vs. 13 groups; Table 4.4). This difference was greater (means 172 vs. 945 m) when additional unuseable sightings were included (Table 4.4). However, the mean CPA during seismic periods may be underestimated if some animals avoided the airgun array at distances beyond those where they could be detected by MMOs, as suggested by lower sighting (and acoustic detection) rates of cetaceans during seismic vs. non-seismic periods (Table 4.3). Thus, the difference in CPAs is likely greater than the data in Table 4.3 suggest. Furthermore, the relatively close mean CPA during non-seismic periods is consistent with the possibility that some delphinids may have been attracted to the *Ewing*. In fact, four episodes of bowriding were observed, and all four were during non-seismic periods. Sample sizes are small, but results from this and some other *Ewing* cruises are consistent with the expectation that seismic sounds displace some cetaceans. The displacement may be related to the size of the airgun array (Smultea et al. 2004; Haley and Koski 2004; MacLean and Koski 2005; Holst et al. 2005).

Categories of Behavior

Cetacean behavior is difficult to observe. Cetaceans are often at the surface only briefly, and there are difficulties in resighting individuals or groups, and in determining whether two sightings some minutes apart are repeat sightings of the same individual(s). Limited behavioral data were collected during this project because cetaceans were often seen at a distance from the vessel, and they were typically not tracked for long distances or times while the vessel was underway. The two parameters that were examined quantitatively to assess potential seismic effects on cetacean behavior were the behavior and movement when they were first observed (see Appendix B for variables and definitions). The CPA distance recorded for each group sighting was also an indicator of behavior (see above and Appendix D).

TABLE 4.4. Closest observed points of approach (CPA) of delphinids to the airgun array during non-seismic and seismic periods during the Chicxulub seismic cruise, 7 Jan.–20 Feb. 2005.

			Non-seismic				Seismic			
Group	Estim. RL[a] at CPA to Airguns	No. of Groups	Mean CPA (m)	s.d.	n	Range (m)	Mean CPA (m)	s.d.	n	Range (m)
Delphinids[b]	≤160 dB	14	172	65	14	87-576	N/A	N/A	0	N/A
	>160 dB	7	N/A	N/A	0	N/A	945	1299	7	107-3783
Useable Delphinids[c]	≤160 dB	13	178	141	13	87-576	N/A	N/A	0	N/A
	>160 dB	6	N/A	N/A	0	N/A	472	383	6	107-996

Note: N/A means data not available.

[a] RL = Received level of airgun sounds (dB re 1 µPa, rms).

[b] Excludes three sightings made during "post-seismic" periods 90 s-6 h after airguns stopped firing.

[c] Useable sightings are those made during useable visual effort as defined in *Acronyms and Abbreviations.*

Sample sizes within this one cruise were too small by themselves to permit meaningful comparisons of behavior during seismic vs. non-seismic periods. However, when combined with results from other cruises, the data may provide indications of behavioral reactions of cetaceans to seismic sounds. Results are presented in Tables 4.5 and 4.6.

First Observed Movement.—"Swim toward" was the first-observed type of movement for 5 of 13 (38%) useable delphinid groups sighted during non-seismic periods, but for 0 of 6 seen during seismic periods (Table 4.5). Most groups (4 of 6) seen during seismic periods were first observed swimming parallel to the *Ewing*.

TABLE 4.5. Comparison of first observed direction of movement by delphinids during non-seismic and seismic periods during the Chicxulub seismic cruise, 7 Jan.–20 Feb. 2005[a]. See Appendix D for definitions of movement categories.

	First Observed Movement						
Group	**Mill**	**Swim Perpen-dicular**	**Swim Away**	**Swim Parallel**	**Swim Toward**	**Unknown**	**Total**
Delphinids[a]							
Non-seismic	2	1	1	2	6	2	**14**
Seismic	-	1	1	4	-	1	**7**
Total	**2**	**2**	**2**	**6**	**6**	**3**	**21**
Useable Delphinids[b]							
Non-seismic	2	1	1	2	5	2	**13**
Seismic	-	1	1	4	-	-	**6**
Total	**2**	**2**	**2**	**6**	**5**	**2**	**19**

[a] Excludes three sightings made during "post-seismic" periods 90 s – 6 h after airguns stopped firing.

[b] Useable sightings are those made during useable visual effort as defined in *Acronyms and Abbreviations*.

TABLE 4.6. Comparison of first observed behavior of delphinid groups during non-seismic and seismic periods during the Chicxulub cruise, 7 Jan.–20 Feb. 2005[a]. See Appendix D.1 for definitions of behavior.

Group	**Porpoising**	**Swimming**	**Unknown**	**Total**
Delphinids [a]				
Non- seismic	4	9	1	**14**
Seismic	-	6	1	**7**
Total	**4**	**15**	**2**	**21**
Useable Delphinids				
Non-seismic	3	9	1	**13**
Seismic	-	6	0	**6**
Total	**3**	**15**	**1**	**19**

[a] Excludes three sightings made during "post-seismic" periods 0–6 h after airguns stopped firing.

[b] Useable detections are those made during useable daylight visual observations as defined in Acronyms and Abbreviations.

First Observed Behavior.—Only two behaviors were observed when delphinids were first seen: swimming/traveling and porpoising. Most of the dolphins seen during both non-seismic and seismic periods were swimming/traveling when first seen (Table 4.6). However, three useable groups seen during non-seismic periods were first seen porpoising (rapid travel with leaping above the water surface) (Table 4.6).

Overall, based on all behaviors recorded (not just initial behavior), 4 of the 24 delphinid groups observed during all conditions exhibited bowriding, all during non-seismic periods (Table F3).

Acoustic Monitoring Results

Passive Acoustic Monitoring Effort

Passive Acoustic Monitoring was conducted for a total of 2935 km (322 h) during the study period (Table ES.1; Appendix F.6). PAM took place during nearly 100% of daytime airgun operations. However, during <1 h of seismic operations, PAM could not be conducted because of technical difficulties with the acoustic array. PAM also occurred during some nighttime conditions, including a 1-h period before seismic operations commenced during mornings, and until complete darkness after seismic operations ended (Table ES.1). Approximately 6% of PAM effort occurred at night, and 94% occurred during the day. Details of PAM effort, partitioned by number of operating airguns, are provided in Appendix F.6.

Acoustic Detections

A total of 13 acoustic detections were made during the Chicxulub cruise (Table ES.1). They ranged in duration from several seconds to 1.7 h; the mean acoustic encounter duration was ~18 min (s.d. = 29 min). Eleven detections were of unidentified dolphins and two were of bottlenose dolphins. In 3 of 13 cases, the acoustic detection could be matched with a visual sighting (Table 4.2). One group was heard and seen simultaneously, one group was first heard and then seen, and another was first seen and then heard via PAM. Three acoustic detections were made during the small amount of nighttime PAM.

Five of the 13 acoustic detections were initially made while the airguns were operating. Three of those detections occurred during operations of the full 20-airgun array, and two others occurred while only one airgun was operating during a power down. All other detections were made when the airguns were not operating. However, on three occasions, the airguns were ramped up when dolphins could still be detected acoustically, when the distance of the dolphins to the airgun array was unknown. On one occasion, 28 Jan., the cessation of dolphin vocalizations coincided with the start of the ramp up.

PAM effort during "non-seismic" periods (66 h) was about one-third that during "seismic" conditions (204 h; Table ES.1). This difference in effort occurred because deployment and retrieval of the SEAMAP hydrophone array usually occurred coincident with deployment and recovery of the airguns. The mean acoustic encounter rate during useable non-seismic periods was more than three times higher than during seismic periods (9.2 vs. 2.7 acoustic encounters/1000 km, respectively; Table 4.3). (The mean visual encounter rate during useable non-seismic periods was more than twice that during seismic periods: 7.6 vs. 3.2 sightings/1000 km, respectively.) During this project, the rates of acoustic and visual detections were similar to one another during both seismic and non-seismic periods.

Discussion

Most acoustic signals that were recorded originated from dolphins and were whistles in the frequency range 8 to 20 kHz. Clicks and click trains were heard on three occasions when dolphins were believed to have approached to within ~200 m of the ship.

During this cruise, no cetaceans were identified to species by their acoustic signals alone. Two groups that were identified as bottlenose dolphins were also detected visually. All other acoustic detections were unidentified. No large whales were detected acoustically (or visually) during the Chicxulub cruise, nor were any detections of large cetaceans expected, given the shallow water where the survey was conducted and what little was known (prior to this survey) about cetacean use of Yucatan waters.

It is evident from the Chicxulub study results (and some previous studies) that at least some cetaceans call in the presence of airgun pulses. However, during this survey, acoustic detection rates were more than three times higher during non-seismic vs. seismic periods. This result is similar to results during previous *Ewing* seismic cruises conducted in 2004 (Smultea et al. 2004, 2005; Holst et al. 2005). It is possible that animals exposed to airgun sounds decreased their sound production rate or intensity, or (in some cases) avoided the *Ewing*, or both. In addition, vessel, airgun and flow noise probably masked detection of some cetacean sounds. However, vessel and flow noise would be similar whether airguns were operating or not, and airgun pulses were present for only a small fraction of the time. Thus, airgun pulses would not be expected to mask more than a small percentage of the calls. Elucidation of these issues will require additional investigation of the effects of airgun and vessel noise on call detection rates, and more generally on the normal acoustic behavior of marine mammals.

Visual detection rates were, during this cruise, similar to acoustic detection rates (Table 4.3). Typically, acoustic detection rates are higher during joint visual/acoustic surveys (Thomas et al. 1986; Fristrup and Clark 1997; Barlow and Taylor 1998; Norris et al. 1999; Smultea et al. 2004, 2005; Holst et al. 2005). However, due to the shallow water in the present study area, it was necessary to tow the acoustic array at a less-desirable and less-effective depth for detecting cetaceans. Thus, during this study, the hydrophones may not have been able to detect cetaceans as far from the vessel as would be possible in deeper water. Also, the species present in this study area (two species of dolphins) may not be detectable as far away as are some of the species present in other areas.

Seasonal, geographic, and diurnal differences are known to affect acoustic detection rates (e.g., Stafford et al. 1998, 1999; Stienessen 1998; Moore et al. 1999). However, factors affecting the acoustic behaviors of cetaceans are generally not well understood, and this complicates the use of PAM and interpretation of PAM results. Variability in vocalization rates and call intensity can dramatically affect detection rates of animals during surveys. In addition, these factors are potentially confounded by the *Ewing*'s presence and its associated seismic activity. Other factors, such as habituation and novelty of the anthropogenic sounds, may also affect acoustic behaviors of cetaceans.

In most circumstances, complementing visual observations with PAM is effective for increasing rates of detections for many species of cetaceans. It is particularly advantageous to conduct PAM at night, when visual monitoring is not very effective. During the Chicxulub cruise, an additional 10 sightings were made solely by acoustic means; three of these occurred at night, despite the limited PAM effort at night. (Nighttime monitoring was not important during this cruise as airgun operations were shut down at night to satisfy a SEMARNAT stipulation.) Given the difficulties in identifying calls to species level, and in localizing the source of the calls, acoustic monitoring still is most effective when combined with visual surveys. When species identification is not a critical component (e.g., for mitigation), then acoustic monitoring without visual confirmation may be acceptable, depending on whether distance of the animal(s) relative to the noise source can be determined with acceptable accuracy. Determination of distance using PAM alone is possible, but has been impractical with the system as deployed from the

Ewing to date. Nighttime and times with poor sighting conditions are situations in which PAM can greatly enhance the ability to detect the presence of calling cetaceans.

Mitigation Measures Implemented

Ramp ups, power downs and shut downs of the airgun array were implemented as mitigation measures during the Chicxulub cruise. Ramp ups were conducted during daylight whenever the airguns were started up after a prolonged period of inactivity, or when there was a requirement to increase the number of operating airguns by a factor exceeding 2× (e.g., from 1 to 20 airguns). The latter occurred subsequent to a power down for a marine mammal or sea turtle seen in or near the safety radii. A total of 56 ramp ups were conducted during the Chicxulub seismic survey: 40 involved a start up from no airguns operating, and the remaining 16 began after a prolonged period (>8 min) with only one airgun operating.

The airguns were fully shut down on one occasion because a single bottlenose dolphin was seen in the safety zone, and on four occasions a power down was implemented. The power downs involved four different delphinid groups including a total of six individual dolphins (Table 4.7; Appendix G): two groups of Atlantic spotted dolphins and two groups of unidentified dolphins. The one shut down and 3 of 4 power downs occurred while the full 20-airgun array was in use. The other power down occurred during a ramp up when eight airguns were operating. All five cases occurred in shallow (<50 m) water where the nominal 180 dB safety radius for the 20-airgun array was 3500 m (Table 3.1).

All power/shut downs were attributable to delphinids that were first observed in the safety zone. For all four power downs, only one or a few shots were fired between the initial detection and the time when the airguns were powered down. However, for the one shut down, numerous airgun shots were fired before the shut down was implemented. Also, in all five cases, the animals were well inside the nominal 180 dB radius when first seen, and had presumably been exposed to strong airgun pulses before the initial sighting. The shut down involved a single bottlenose dolphin first seen by bridge personnel as it swam slowly across the *Ewing*'s bow at a distance of ~107 m from the airguns (Table 4.7). The five power/shut down occasions are described in detail in Appendix G. The maximum sound levels received by some if not all of these five groups of delphinids probably were ≥180 dB re 1 μPa (rms) for some of the airgun shots prior to the power downs or shut down. This assumes that the animals, while inside the safety radius, were well below the surface when one or more of the airgun pulses were received.

Estimated Number of Marine Mammals Potentially Affected

It is difficult to obtain meaningful estimates of "take by harassment" for several reasons: ***(1)*** The relationship between numbers of marine mammals that are observed and the number actually present is uncertain. ***(2)*** The most appropriate criteria for "take by harassment" are uncertain and presumably variable among species and situations. ***(3)*** The distance to which a received sound level exceeds a specific criterion such as 190 dB, 180 dB, 170 dB, or 160 dB re 1 μPa (rms) is variable. It depends on water depth, airgun depth, and aspect for directional sources (Greene 1997; Greene et. al. 1998; Burgess and Greene 1999; Caldwell and Dragoset 2000; Tolstoy et al. 2004a,b). ***(4)*** The sounds received by marine mammals vary depending on their depth in the water, and will be considerably reduced for animals at or near the surface (Greene and Richardson 1988; Tolstoy et al. 2004a,b).

TABLE 4.7. List of power downs (PD) and shut downs (SZ) of the airguns implemented for cetaceans sighted in the safety radii during the Chicxulub cruise, 7 Jan.–20 Feb. 2005. All of these PD and SZ occurred for presumably different individual dolphins.

Species	Group size	Date (2005)	Water depth (m)	Movement[a]	Dove? (Yes/No)	No. of airguns on prior to SZ or PD	Total airgun volume prior to SZ or PD (in^3)	Approx. 180-dB radius (m)	CPA(m) to operating airguns before mitigation	Mitigation measure taken (PD or SZ)	Maximum potential received sound level (dB)	No. indiv. exposed to >180 dB re 1 µPa (rms)[b]	Likelihood of exposure to ≥180 dB
Atlantic spotted dolphin	2[c]	24 Jan	18	SP	No	8[d]	1400	2000	303	PD	>180 dB	2	very likely
Unidentified dolphin	1	1 Feb	15	SP	No	20	6970	3500	1039	PD	>180 dB	1	very likely
Atlantic spotted dolphin	2	9 Feb	16	SP	No	20	6970	3500	676	PD	>180 dB	2	very likely
Bottlenose dolphin	1	17 Feb	28	PE	No	20	6970	3500	107	SZ	>180 dB	1	definite
Unidentified dolphin	1	17 Feb	25	SA	No	20	6970	3500	2033	PD	>180 dB	1	very likely

[a] Initial movement of group relative to the vessel: SP = swimming parallel, PE = swimming perpendicular (across bow), SA = swimming away.

[b] Number of individuals that came within estimated 180 dB radius for the number and volume of airguns in use at the time (see text for details).

[c] One adult and one juvenile.

[d] Seen during ramp up.

Disturbance and Safety Criteria

Any cetacean that might have been exposed to airgun pulses with received sound levels ≥160 dB re 1 μPa (rms) was, in one set of calculations that follow, assumed to have been potentially disturbed. Such disturbance was authorized by the IHA issued to L-DEO. However, the 160 dB criterion was developed by NMFS from studies of baleen whale reactions to seismic pulses (Richardson et al. 1995). That criterion likely is not appropriate for delphinids. The hearing of small odontocetes is relatively insensitive to low frequencies, and behavioral reactions of small odontocetes to airgun sounds indicate that they are less responsive than are some baleen whales (Richardson et al. 1995; Gordon et al. 2004; LGL Ltd. 2003a,b). Probable exposure to received levels ≥170 dB was used as an alternative criterion in estimating potential disturbance of delphinids.

Table 3.1 shows the radii at which various sound levels are estimated to be received in shallow (<100 m) water from a single 80 in^3 airgun and a 20-airgun array with volume 8600 in^3. The predicted 160 and 170 dB radii (disturbance criteria for marine mammals) are based on modeling and limited acoustic measurements for shallow waters of the northern Gulf of Mexico (Tolstoy et al. 2004a,b).

During the present project, NMFS required that mitigation measures be applied to avoid or minimize the exposure of cetaceans (and sea turtles) to impulse sounds with received levels ≥180 dB re 1 μPa (rms). The safety radii used during the Chicxulub study were presented in Table 3.1. The safety radius used for the 20-airgun array during the Chicxulub cruise (3500 m; Table 3.1) represents the best estimate of the 180 dB distance for a 20-airgun array with 8600 in^3 total volume.

This distance, and the corresponding estimated distances for received levels of 160, 170 and 190 dB, were used to estimate numbers of cetaceans exposed to various received sound levels. The distances for a 20 airgun array with total volume 6970 in^3 (as actually used in this study) would be marginally smaller, but the estimated distances for the 8600 in^3 array were used here.

This section applies several methods to estimate the number of marine mammals exposed to seismic sound levels strong enough that they might have caused disturbance or other effects. The procedures include ***(A)*** minimum estimates based on direct observations, ***(B)*** estimates based on marine mammal densities obtained in the study area via visual observations from the *Ewing* during periods unaffected by seismic surveys, and ***(C)*** estimates based on densities obtained by observers aboard the *Ewing* while seismic surveys were being conducted in the study area. The actual number of individual marine mammals exposed to, and potentially affected by, seismic survey sounds likely was between the minimum and maximum estimates provided below. The estimates provided here are based on observations during this project. In contrast, the estimates provided in the IHA Application and EA for this project (LGL Ltd. 2003a,b) were based on survey and other information available prior to this project.

Estimates from Direct Observations

The number of cetaceans observed close to the *Ewing* during the Chicxulub seismic survey provides a minimum estimate of the number potentially affected by seismic sounds. This is likely an underestimate of the actual number potentially affected. Some animals probably moved away before coming within visual range, and not all of those that remained would have been seen by observers even though seismic operations occurred only during the daytime. It is assumed that no pinnipeds were affected by seismic sounds, as no pinnipeds were expected or seen during the Chicxulub cruise.

Cetaceans Potentially Exposed to Sounds ≥180 dB re 1 µPa (rms).—During this project, five different cetacean groups involving seven different individual delphinids were first sighted within the safety radius around the airguns; a power down or shut down was undertaken for all five of these occasions (Table 4.7; Appendix G). The sound levels received by all five delphinid groups may have exceeded 180 dB prior to the shut down or power downs.

The estimated 180-dB radii shown in Table 3.1 are the *maximum* distances from the airgun array where sound levels were expected to be ≥180 dB re 1 µPa (rms). These distances would apply at the water depth with maximum received level and in the direction (from the airgun array) where the sounds were strongest. Thus, there are complications in assessing the maximum level to which any specific individual mammal might have been exposed:

- Near the water surface, received sound levels are considerably reduced because of pressure-release effects. In many cases, it is unknown whether animals seen at the surface were earlier (or later) exposed to the maximum levels that they would receive if they dove.
- For bowriding dolphins observed at or near the surface for extended periods, the received airgun sounds would remain reduced relative to levels at deeper depths. However, dolphins that were observed to bow-ride may have been at depth for portions of the time while they were within the safety radius.
- Because the airguns were aligned in the cross-track direction, their sounds were stronger in the fore-aft direction than in the cross-track direction (see Fig. B.1 in Appendix B). We have assumed that the 180 dB distance was as far to the side as it was fore and aft, which will overstate the levels to which certain animals were exposed.
- Some cetaceans may have been within the predicted 180 dB radii and/or within the safety radii while underwater and not visible to observers, and subsequently seen outside these radii. The direction of movement as noted by MMOs can give some indication of this.
- The MMO station on the flying bridge was ~89 m forward of the airguns in their normal configuration, and the tip of the *Ewing*'s bow was ~104 m away from the nearest airgun. Therefore, the nominal safety zone was not centered on the observer's station, but rather on the center of the airgun array. This difference was accounted for in the observer's decisions regarding whether it was necessary to shut down the airguns for sightings immediately forward or astern.

Delphinids Potentially Exposed to Sounds ≥160 dB re 1 µPa (rms).—Seven groups of cetaceans (all delphinids) were sighted during the Chicxulub cruise when the airguns were operating (Appendices F.3 and F.4). Two delphinid groups were seen when 1 airgun was operating, one group was seen during a ramp up when 8 airguns were operating, and the remaining four groups were seen while 20 airguns were firing. All seven groups (13 different individuals) were believed to be unique groups that entered the ≥160 dB radius (see Table F.3 for sightings). All these groups were in shallow water (<50 m). They include the five groups that caused power and shut downs as discussed earlier. However, because the estimated 160 dB radius for 20 airguns (12 km) is well beyond the effective sighting distance of the observers, one can assume that many delphinids (and possibly some other cetaceans) that were exposed to those sound levels were not seen by observers. These missed animals are accounted for in estimates presented later in this section based on densities of animals during seismic and non-seismic periods. However, any delphinids exposed to received levels of ~160–170 dB re 1 µPa (rms) may not have been disturbed significantly as discussed below.

Delphinids Potentially Exposed to Sounds ≥170 dB re 1 µPa (rms).—For delphinids, exposure to airgun sounds with received levels ≥170 dB may be a more appropriate criterion of disturbance than exposure to ≥160 dB as described above. All seven delphinid groups involving 13 dolphins seen while airguns were operating (Table 4.7), were observed where received levels of airgun sounds below the surface were estimated to be ≥170 dB. This includes the five groups for which power/shut downs were implemented. The two remaining groups were seen outside the safety radius so no mitigation was required (Appendix F.3). Again, because the estimated 170 dB radius for 20 airguns (7 km) is well beyond the effective sighting distance of the observers, many delphinids and possibly some other cetaceans that were exposed to ≥170 dB would not have been seen by the observers.

Estimates Extrapolated from Marine Mammal Density

The number of marine mammals sighted during the Chicxulub survey presumably underestimates the actual number present during the survey because some animals present near the trackline would not be seen by the observers. During daylight, this occurs if the animals were below the surface when the ship was nearby. Some other mammals, even if they surfaced near the vessel, would be missed because of limited visibility, high Bf, glare, or other factors limiting sightability.

Furthermore, some animals would be expected to avoid the area near the seismic vessel while the airguns were firing (see Richardson et al. 1995; Stone 2003; Gordon et al. 2004; Smultea et al. 2004). In addition, during this project with a 20-airgun array operating in shallow water, observers were unable to survey effectively out to distances much beyond the estimated 180 dB re 1 μPa (rms) radius of 3500 m even during good-visibility periods. The ability to detect cetaceans within and beyond ~2–3 km was likely reduced, especially for smaller animals and small groups, during less than ideal viewing conditions. Only one of the 24 cetacean sightings was determined to be >3500 m from the *Ewing* (Appendix F.3). Within the assumed 160–170 dB radii around the source (i.e., ~7–12 km), the distribution and behavior of cetaceans likely was altered as a result of the seismic survey. Thus, in comparison with results from a project involving a smaller airgun system, observations during seismic operations reported here likely underestimate the number of animals that would have been present in the absence of seismic operations.

The methodology used to estimate the areas exposed to received levels ≥160 dB, ≥170 dB, ≥180 dB and ≥190 dB, and to estimate corrected marine mammal densities, was described briefly in Chapter 3 *Analyses* and in further depth in Appendix D. Densities based on the number of sightings made during the cruise were calculated for both non-seismic and seismic periods. The former represent the densities of mammals expected to occur "naturally" within the area. The latter represent the densities of mammals that apparently remained within the area exposed to strong airgun pulses.

The aforementioned corrected densities were used to estimate both the number of *individual* marine mammals exposed to 160, 170 and 180 dB, and the number of *exposures* of different individual marine mammals. These numbers provide estimates of the number of cetaceans potentially affected by seismic operations, as described in Chapter 3 and Appendix D. Because no pinnipeds were seen during the Chicxulub survey, and their occurrence is considered unlikely in the region, the estimated number of pinnipeds exposed was zero and pinnipeds are not discussed further.

Table 4.8 is a summary of the estimated numbers of cetaceans exposed to received airgun sounds ≥160 dB and ≥170 dB relative to the number of "takes" requested in the IHA Application. A similar summary of estimated marine mammal exposures to airgun sounds ≥180 dB and ≥190 dB is provided in Table 4.9. The data used to calculate these numbers, for non-seismic as well as seismic periods, are presented in Appendices H.1–H.5 for the criteria of interest.

TABLE 4.8. Estimated numbers of exposures, and estimated minimum number of individual marine mammals exposed, to airgun sounds with received levels ≥160 dB (and ≥170 dB for delphinids) re 1 µPa (rms), based on observed densities during non-seismic and seismic periods during the Chicxulub survey. Also shown is the "harassment take" authorized by NMFS under the IHA. Species in italics are listed under the ESA as endangered.

	Estimated numbers exposed to ≥160 dB re 1 µPa (rms) (and ≥170 dB) based on observations during **non-seismic periods** [1]		Estimated numbers exposed to ≥160 dB re 1 µPa (rms) (and ≥170 dB) and based on observations during **seismic periods** [1]		Requested take
	Exposures	Individuals	Exposures	Individuals	
Odontocetes					
Delphinidae					
Rough-toothed dolphin	0 (0)	0 (0)	0 (0)	0 (0)	443
Bottlenose dolphin	1023 (496)	344 (207)	170 (83)	57 (34)	13,660
Pantropical spotted dolphin	0 (0)	0 (0)	0 (0)	0 (0)	654
Atlantic spotted dolphin	865 (420)	291 (175)	113 (55)	38 (23)	1481
Spinner dolphin	0 (0)	0 (0)	0 (0)	0 (0)	100
Clymene dolphin	0 (0)	0 (0)	0 (0)	0 (0)	100
Striped dolphin	0 (0)	0 (0)	0 (0)	0 (0)	100
Short-beaked common dolphin	0 (0)	0 (0)	0 (0)	0 (0)	5
Long-beaked common dolphin	0 (0)	0 (0)	0 (0)	0 (0)	5
Fraser's dolphin	0 (0)	0 (0)	0 (0)	0 (0)	100
Risso's dolphin	0 (0)	0 (0)	0 (0)	0 (0)	10
Unidentified dolphin	786 (381)	264 (159)	57 (28)	19 (11)	
Melon-headed whale	0 (0)	0 (0)	0 (0)	0 (0)	100
Pygmy killer whale	0 (0)	0 (0)	0 (0)	0 (0)	15
False killer whale	0 (0)	0 (0)	0 (0)	0 (0)	539
Killer whale	0 (0)	0 (0)	0 (0)	0 (0)	10
Short-finned pilot whale	0 (0)	0 (0)	0 (0)	0 (0)	308
Long-finned pilot whale	0 (0)	0 ()	0 (0)	0 (0)	5
Total Delphinidae	**2674 (1297)**	**899 (542)**	**340 (165)**	**114 (69)**	**17,635**
Physeteridae					
Sperm whale	*0*	*0*	0	*0*	*10*
Dwarf/Pygmy sperm whale	0	0	0	0	10
Ziphiidae					
Cuvier's beaked whale	0	0	0	0	10
Sowerby's beaked whale	0	0	0	0	10
Gervais' beaked whale	0	0	0	0	10
Blainville's beaked whale	0	0	0	0	10
Mysticetes					
North Atlantic right whale	*0*	*0*	*0*	*0*	*2*
Humpback whale	*0*	*0*	*0*	*0*	*2*
Minke whale	0	0	0	0	2
Bryde's whale	0	0	0	0	5
Sei whale	*0*	*0*	*0*	*0*	*2*
Fin whale	*0*	*0*	*0*	*0*	*2*
Blue whale	*0*	*0*	*0*	*0*	*2*
Total Other Cetaceans	**0**	**0**	**0**	**0**	**77**
Total Cetaceans	**2674**	**899**	**340**	**114**	**17,712**

[1] Survey effort, numbers of sightings and corrected densities on which these estimates arre based are provided in Appendices H.1 (non-seismic periods) and H.3 (seismic periods).

TABLE 4.9. Estimated numbers of exposures, and estimated minimum numbers of individual marine mammals exposed, to airgun sounds with received levels ≥180 dB (and ≥190 dB for delphinids) during the Chicxulub cruise, 7 Jan.–20 Feb. 2005. Based on calculated densities[a] in seismic periods (e.g., Appendix H.3). Sound sources were 1 to 20 airguns with total volume of 80 to 6970 in^3. Received levels of airgun sounds are expressed in dB re 1 μPa (rms, averaged over pulse duration).

Species/species group	Exposures [a]		Individuals [a]	
Odontocetes				
Delphinidae				
Bottlenose dolphin	37	(20)	21	(14)
Atlantic spotted dolphin	25	(14)	14	(9)
Unidentified dolphin	12	(0)	7	(5)
Total Delphinidae	**74**	**(34)**	**41**	**(28)**
Physeteridae	0		0	
Ziphiidae	0		0	
Mysticetes	0		0	
Total Non-Delphinidae	**0**		**0**	
Total Cetaceans	**74**		**41**	

[a] Slight apparent discrepancies in totals result from rounding to integers.

***Estimated Numbers of Cetaceans Exposed to ≥160 or ≥170 dB*.**—It is assumed that non-delphinid cetaceans are likely to be disturbed appreciably if exposed to received levels of seismic pulses ≥160 dB re 1 μPa (rms). It is assumed that delphinids are unlikely to be disturbed appreciably unless exposed to received levels ≥170 dB. These are not considered to be "all-or-nothing" criteria; some individual mammals may react strongly at lower received levels, but others are unlikely to react strongly unless levels are substantially above 160 or 170 dB.

Estimates Based on Densities during Non-seismic Periods: "Corrected" estimates of the densities of cetaceans present during non-seismic periods are given in Appendices H.1 and H.2. These corrected densities were used to estimate the number of cetaceans that were exposed to ≥160 and ≥170 dB, and thus potentially disturbed by seismic operations (Table 4.9).

(A) 160 dB (rms): We estimate that there would have been ~2674 exposures of ~899 different individual delphinids to ≥160 dB during the Chicxulub survey if the cetaceans remained stationary throughout the study (Table 4.9). The "exposures" estimate would be reasonable if cetaceans did not react to the approaching seismic vessel. The "individuals" estimate would be reasonable if there was no reaction, and if cetaceans remained stationary throughout the study. Both of these assumptions are unlikely. The actual numbers of individuals that were exposed to ≥160 dB re 1 μPa (rms), or that moved away in response to the approaching seismic vessel before levels reached 160 dB, are expected to be somewhere between the "exposures" and "individuals" estimates shown in Table 4.9.

(B) 170 dB (rms): On average, delphinids may be disturbed only if exposed to received levels of airgun sounds ≥170 dB re 1 μPa (rms). If so, then the estimated number of exposures of delphinids would be approximately one half of the delphinid estimates for ≥160 dB, based on the proportionally smaller

areas exposed to ≥170 dB than ≥160 dB in the shallow water where all seismic surveys were conducted (see Appendix D.2). Overall, based on densities estimated from surveys during non-seismic periods, the estimated number of delphinid exposures to ≥170 dB was ~1297, which is ~49% of the expected exposures to ≥160 dB (2674). The number of individual delphinids exposed to ≥170 dB (or that moved away before the received level reached 170 dB) is estimated as ~542 or ~60% of the number of individual delphinids exposed to ≥160 dB.

Estimates Based on Densities during Seismic Periods: The densities of cetaceans during seismic periods (5.0/1000 km^2; Appendix H.3) were ~1/8th of those during non-seismic periods (39.6/1000 km^2; Appendix H.1). This was likely due to movements of cetaceans away from the active seismic vessel during seismic periods. Because observers were able to effectively monitor animals only within ~3 km of the seismic vessel, but received levels of seismic sounds exceeded 160 dB to ~12 km, densities calculated from observations during seismic periods likely underestimate numbers of animals exposed to ≥160 dB. Some animals may have moved >3 km from the source vessel but remained <12 km from it. In any event, based on the corrected densities recorded during seismic periods, the minimum numbers of exposures and minimum numbers of individuals exposed are summarized in Table 4.9. For additional details, see Appendices H.3 and H.5.

Cetaceans Potentially Exposed to Sounds ≥180 dB.—It is likely that some cetaceans that were at the surface within the relatively large (3500 m) 180 dB radius for the 20-airgun array during daylight observation periods would have been missed by the observers. Based on the densities of cetaceans estimated from observations during seismic periods, ~74 cetacean exposures and 41 individuals would have been expected to occur within the 180 dB radius around the operating airguns (Table 4.10). The latter estimate is about seven times higher than the seven different individual cetaceans that direct observations indicated were likely exposed to ≥180 dB (Table 4.7). However, the ~41–74 estimates exclude any animals near the seismic vessel that were below the surface or were missed for other reasons. Also, note that these estimates exclude animals that avoided exposure to ≥180 dB by swimming away from the approaching seismic vessel.

Summary of Exposure Estimates.—Estimates of the numbers of exposures to strong sounds are considered *maximum* estimates of the number of mammals exposed. In this method, repeated exposures of some of the same animals are counted separately, with no allowance for overlapping survey lines. This method, when based on densities during non-seismic periods, also assumes that no mammals show avoidance of the approaching seismic vessel before received sound levels reach the sound level in question. Based on corrected densities of cetaceans observed during non-seismic periods, a maximum of ~2674 potential cetacean exposures to airgun sounds with received levels ≥160 dB re 1 μPa might have occurred during the seismic survey. The estimates are lower if based on number of individuals exposed to ≥160 dB (~899), or if the alternative ≥170 dB criterion is applied for delphinids (Table 4.9); 542 individual delphinids are estimated to have been exposed to ≥170 dB.

The highest overall estimate of exposures to ≥160 dB (n = 2674) is only about 15% of the potential "take" estimated in the IHA Application, and the 899 individuals is only about 5% of the estimated take. There are two reasons for the difference. First, the requested take authorization was based on ***maximum*** numbers of marine mammals that might occur in the survey area during the survey period, an approach that tends to overestimate the number ***likely*** to be there. Second, less seismic surveying was done than was assumed in the IHA Application because SEMARNAT prohibited seismic surveys during darkness. Note that the 2674 estimate *does* include approximate allowance for animals missed by the observers during daytime. That allowance is based on application of "best available" correction factors for missed animals (i.e., $f(0)$ and $g(0)$ factors) during daytime.

Summary and Conclusions

L-DEO's Chicxulub marine mammal monitoring program provided concentrated survey effort near the northern Yucatán Peninsula in the little-studied shallow waters of the southern Gulf of Mexico. Over 4280 km of daylight visual observation effort, and 2935 km of primarily (94%) daylight PAM were conducted during the cruise; ~83% of visual effort was during "useable" conditions. Behavior and density analyses were conducted with "useable" sightings, consisting of an estimated 92 delphinids in 19 groups. No injured marine mammals potentially associated with the operations were sighted.

Three different cetacean species were identified during the study; the remaining sightings were unidentified dolphins. As expected, given the shallow waters of the study area, the Atlantic spotted dolphin (n = 7 groups) and bottlenose dolphin (n = 6 groups) were the most commonly seen species. They were the only species detected in the area off the northwestern Yucatán Peninsula where the actual seismic survey was done. The one other species identified during the cruise was the pantropical spotted dolphin (n = 1 group), which was seen in deep water during transit to the survey area.

The small number of useable sightings (n = 19), particularly during seismic periods (n = 6), limits meaningful interpretation of results. However, trends based on this small sample are generally consistent with those during other seismic studies conducted from the *Ewing*. These observations suggest that the large seismic sound source used during this cruise may have displaced or affected the behavior of some cetaceans within view of observers on the *Ewing*. Bowriding delphinids were seen on four occasions, all during non-seismic periods.

A total of 13 acoustic detections were made during the Chicxulub survey (all delphinids, 85% of which were unidentified dolphins). Although the sample sizes are small, acoustic detection rates were similar to visual detection rates during both seismic and non-seismic periods. Acoustic detection rates were lower during seismic vs. non-seismic periods, as in past cruises. The Chicxulub acoustic monitoring results (and some previous studies) also indicate that at least some cetaceans call in the presence of airgun operations.

During this project, seven delphinid groups involving 13 individuals were seen during seismic operations. Four power downs and one shut down were initiated when five of these delphinid groups (seven individual dolphins) were seen within the designated safety radii. Based on direct observations, the number of delphinids estimated to have been exposed to various sound levels was as follows.

- At least 7 of the 13 dolphins seen during seismic periods are very likely to have been exposed to airgun sounds with received levels ***≥180 dB*** re 1 µPa (rms), given that they were seen well within the safety radii in shallow water depths (~15–28 m).
- All 13 of the individual delphinids seen during seismic periods were seen where received levels were estimated to be ***≥170 dB***; and thus also ***≥160 dB***. The 170-dB radius is considered a realistic estimate of the received seismic sound level at which delphinids may be potentially disturbed by seismic sounds .

Additional cetaceans, most likely delphinids, were probably present within the ≥160 or ≥170 dB zones during daytime seismic operations but were beyond view of the observers.

Densities of marine mammals within the seismic study area were estimated based on "useable" survey data from seismic and non-seismic periods in water depth <100 m. Estimated densities during seismic surveys were ~1/8th those during non-seismic periods. Sample sizes were low, but the difference in observed densities during seismic and non-seismic periods suggests that, during seismic periods, some delphinids moved away from the seismic vessel before they could be seen by MMOs.

Minimum and maximum estimates of numbers of cetaceans in areas exposed to airgun sounds are shown in Table 4.9 based on the densities estimated from surveys during seismic and non-seismic periods. Also shown, for comparison, are the numbers of "harassment takes" that were requested by L-DEO in the IHA Application. All estimates based on actual density data are lower than the "harassment takes" estimated prior to the survey. At most, the estimated number of cetacean exposures to ≥160 dB was ~15% of the maximum estimated in the IHA Application. The number of different individuals exposed was estimated as ~5% of that pre-survey estimate.

Overall, the results show that the marine mammal community of the shallow waters northwest of the Yucatán Peninsula is not diverse, with only two common species of dolphins. The results suggest that, when the large array of airguns was operating, some delphinids avoided the seismic vessel, possibly by as much as several km, or that some animals changed their behavior in ways that made them less conspicuous to observers. The radius of effect is uncertain, but appears to have extended at least out to 2–3 km or more, which is the distance within which MMOs were able to sight marine mammals with reasonable reliability in the conditions experienced during this survey. The radius of effect during this survey with a 20-airgun array appears to have been much larger than during similar surveys using 1–3 GI guns (Haley and Koski 2004; MacLean and Koski 2005; Holst et al. 2005).

5. SEA TURTLES

Introduction

This chapter describes the results of the sea turtle monitoring program. It begins with a review of the status of sea turtles occurring in the study area off the Yucatán Peninsula, and then presents the results of the sea turtle monitoring program. The chapter ends with a brief summary and conclusions section. An overview of program operations was provided in Chapter 2, and the mitigation and monitoring programs were described in Chapter 3. A list of all sea turtle sightings during the Yucatán cruise is provided in Appendix I.1.

Status of Sea Turtles in the Area

Several species of sea turtles are known to occur in the surveyed area off the Yucatán Peninsula: the loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*), and Kemp's ridley turtle (*Lepidochelys kempii*). The olive ridley turtle (*L. olivacea*) ranges through the Caribbean Sea, south to Central and South America, and does not usually range into the southern Gulf of Mexico (Euroturtle 2001). Beaches in Campeche (western Yucatán Peninsula), Yucatán (study area location), and Quintana Roo (eastern Yucatán Peninsula) harbor rookeries for hawksbill, green, and loggerhead turtles. Kemp's ridley turtles only breed along the Tamaulipan coast in the western Gulf of Mexico (Arenas et al. 2003).

The loggerhead and green sea turtles are currently listed as *Threatened* under the ESA, and the leatherback, Kemp's ridley, and hawksbill sea turtles are listed as *Endangered*. The IUCN-World Conservation Union Red List (IUCN 2002) classifies Kemp's ridley, leatherback, and hawksbill turtles as *Critically Endangered*, and loggerhead and green turtles as *Endangered*. Mexico and the United States are both signatories of InterAmerican Convention for the Protection and Conservation of Marine Turtles.

Sea turtles share a common life cycle with slight variations among species (see Miller 1997). All species migrate between foraging areas and nesting areas. Migration routes may exceed 2600 km, but most sea turtles travel less than 1000 km (Miller 1997). Females of most species nest every two to four years; however, females of some species nest annually. After mating, males generally return to feeding areas while females come ashore at select beaches to lay eggs. Over the next few months, females lay up to 10 clutches of about 100 eggs in buried nests on beaches. The eggs incubate for about two months, and then the hatchlings move into the sea where they begin their extended pelagic phase of development. Later, juveniles of most species enter the coastal zone or move into bays and estuaries, where they mature 10 to 50 years later.

Sea turtles spend most of their time at sea and generally only return to land to nest. Most species are widely distributed, but their habitat preferences vary. All except the leatherback turtle and some populations of green turtles are believed to be primarily coastal when not breeding (EuroTurtle 2001). The leatherback sea turtle is highly oceanic and only occurs in coastal areas during the breeding season. Feeding habitats include coral reefs and seagrass beds. Sea turtles are known to feed and nest off the Yucatán Peninsula. However, the main breeding season (Apr.–Sep.) did not overlap with the study period (Jan.–Feb.).

The descriptions of sea turtles below are mainly based on information from Márquez (1990) and UNEP technical reports (Horrocks 1992; Sybesma 1992; Barmes et al. 1993; UNEP 1993; d'Auvergne and Eckert 1993).

Loggerhead Turtle (Caretta caretta)

The loggerhead turtle, listed as *Threatened* under the ESA, is a widely distributed species occurring in coastal tropical and subtropical waters around the world. Loggerhead turtles undertake long migrations that take them far from their breeding grounds, possibly using warm water currents such as the Gulf Stream. Loggerheads may be seen in the open seas during these migrations. Loggerhead turtles prefer to feed in coastal bays and estuaries, as well as in the shallow waters along the continental shelves of the Atlantic, Pacific, and Indian Oceans. Adult loggerheads feed on a variety of benthic fauna such as conchs, crabs, shrimp, sea urchins, sponges, and fish. During the migration through the open sea, they feed on jellyfish, pteropods, floating mollusks, floating egg clusters, flying fish, and squid.

In the Atlantic, major nesting areas include the southeastern USA, as well as the Yucatán Peninsula of Mexico, Columbia, Cuba (EuroTurtle 2001), and the Atlantic coast from Venezuela to Brazil. A major nesting site for loggerhead turtles is located at X'cacel, Quintana Roo, Mexico—about 100 km south of Cancún. It has the highest density of sea turtle nests (of several species) per kilometer of beach (160 nests/km) in the entire region, and its 86% hatchling survival rates is one of the highest known (Sea Turtle Survival League 1998). The nesting season of this sea turtle is typically from May to Aug. (USFWS 2003), and as such did not overlap with the study period. During or shortly after the breeding season, females disperse to distant feeding grounds via poorly delineated migration routes.

The global population of loggerhead turtles is estimated at 60,000 nesting females (data from nesting beach monitoring reports from the 1990s; Sea Turtle Survival League 1995b).

Green Sea Turtle (Chelonia mydas)

Green sea turtles, listed as *Threatened* under the ESA, are widely distributed in tropical and subtropical waters near continental coasts and around islands. Green sea turtles typically migrate along coastal routes from rookeries to feeding grounds, although some populations conduct trans-oceanic migrations (e.g., Ascension Island–Brazil). Females typically show nest site fidelity, and nest in the same spot as their last clutch, or on the same beach from which they hatched. Hatchlings are epipelagic (surface dwelling in the open sea) for ~1–3 years. They live in bays and along protected shorelines and feed during the day on seagrass and algae (Bjorndal 1982). Juvenile and sub-adult green turtles travel extensively and may travel thousands of kilometers before they return to breeding and nesting grounds (Carr et al. 1978).

Major nesting beaches in the Atlantic occur in Mexico, Costa Rica, Venezuela, and Surinam (EuroTurtle 2001). The northern coastline of the Yucatán Peninsula is identified as a minor nesting site for this sea turtle (Sea Turtle Survival League 1995a). However, there is an important nesting site at X'cacel ~100 km south of Cancun on the east coast of the Yucatán Peninsula (Quintana Roo). X'cacel has one of the highest densities of sea turtle nests (of several species) in the western hemisphere and a high hatchling survival rate (~86%). The nesting season of the green sea turtle is typically in May and June. (Earlham College 2001), and did not overlap with the study period. Adult green turtles may be present in the region year-round.

The green sea turtle population is estimated at 203,000 nesting females (Sea Turtle Survival League 1995a).

Hawksbill Sea Turtle (Eretmochelys imbricata)

Hawksbill sea turtles, listed as *Endangered* under the ESA, are the most tropical of all sea turtles; nesting is confined to areas where water temperature is 25º–35ºC. Non-nesting hawksbill turtles are known as far north as Cape Cod. Hawksbill turtles are observed in shallow waters with seagrass or algal meadows, and are most common where reef formations are present. They live in clear, littoral waters of mainland and island shelves. Post-hatchlings are believed to be pelagic, taking shelter in weed lines around convergence zones. They re-enter coastal waters once attaining a length of ~20–25 cm. Coral reefs are the resident foraging grounds for juvenile hawksbills sea turtles. These turtles nest on low and high energy beaches, often sharing high energy locations with green sea turtles. Hawksbill turtles most commonly perform short-distance movements between nesting beaches and offshore feeding banks, although long-distance movements are also known.

The most important nesting beaches in the Atlantic are along the Yucatán Peninsula of Mexico, Panama, southern Cuba, and a few Caribbean islands (EuroTurtle 2001). Female hawksbill sea turtles nest at intervals of two or more years. Hawksbill nesting beaches on the Yucatán Peninsula include those located along the coastline of Campeche (western shoreline of Yucatán Peninsula), and at Las Coloradas, Isla Holbox and Rio Lagartos in the state of Yucatán (Meylan 1999). The hawksbill turtle nesting season is ~6 months in duration. Nesting generally occurs between July and Oct., preceded by courtship and mating. Hawksbill turtles are known to feed year-round in the study area. They feed primarily on coral-reef-associated sponges, anemones, squid and shrimp, corals, tunicates, and algae.

The worldwide population estimate for Hawksbill turtles is 8000 nesting females (Sea Turtle Survival League 1995c).

Kemp's Ridley Turtle (Lepidochelys kempii)

Kemp's ridley turtles, listed as *Endangered* under the ESA, have a more restricted distribution than most other sea turtles. Adult Kemp's ridley turtles nest only in the Gulf of Mexico and remain there year-round, migrating along the coast between nesting beaches and feeding areas. Juveniles, however, range between the tropics and temperate coastal areas of the western Atlantic, as far as New England. Occasionally individuals may be carried by the Gulf Stream as far as northern Europe, although those individuals are considered lost to the breeding population. Kemp's ridley turtles nest from April to June along the Tamaulipas and Veracruz coasts of Mexico (western and southwestern Gulf of Mexico). The preferred sections of nesting beach are backed up by extensive swamps or large bodies of open water having seasonal narrow ocean connections. Outside of nesting habitat, the major habitat for this sea turtle is the nearshore and inshore waters of the northern Gulf of Mexico, especially Louisiana waters. They are often found in salt marsh habitats. Kemp's ridley turtles feed on crabs, shrimp, gastropods, clams, urchins, jellyfish, squid eggs, and fish.

The worldwide population of Kemp's ridley turtles is estimated at less than 1000 nesting females (Sea Turtle Survival League 1995d).

Leatherback Turtle (Dermochelys coriacea)

Leatherback turtles, listed as *Endangered* under the ESA, are the largest and most widely distributed sea turtles and range far from their tropical and subtropical breeding grounds. Leatherbacks are highly pelagic and approach coastal waters only during the reproductive season (EuroTurtle 2001). Leatherbacks appear to migrate along bathymetric contours ranging from depths 200 to 3500 m. Leatherbacks feed mainly on jellyfish, tunicates, and other epipelagic soft-bodied invertebrates (Hartog and van Nierop 1984; Davenport and Balazs 1991).

In the Atlantic, most leatherbacks nest in Venezuela, the Caribbean islands, Columbia, Surinam, French Guiana, Costa Rica, and Panama. Minor nesting sites occur on the southeastern Yucatán Peninsula and in the southwestern section of Campeche Bay. Thus, leatherback turtle nesting beaches were located a considerable distance from the project area. In the northern Atlantic, the breeding season begins in March and continues through July. Females may lay up to 9 clutches in a season, although 6 is more usual. The incubation period is 58–65 days.

The leatherback turtle population is estimated at 34,000 nesting females (Sea Turtle Survival League 1995e).

Monitoring and Mitigation

Monitoring and mitigation requirements for sea turtles, as identified in the IHA (Appendix A) and SEMARNAT, are summarized in Chapter 3 along with those for marine mammals. For this project, the IHA required that ramp up of the airguns be delayed if a sea turtle was seen within the safety radius. Also, it required that the airguns be powered down or shut down if a turtle was seen within or about to enter the 180 dB safety radius while the airguns were operating. Observers diligently monitored for sea turtles near the *Ewing* during all airgun operations, as required by the IHA. Because of the restrictions from SEMARNAT, no nighttime operations or watches were conducted.

Visual Monitoring Results

Sea Turtle Sightings

A total of 29 sea turtle sightings involving 29 individuals occurred from the *Ewing* during the Chicxulub cruise (Fig. 5.1; Table 5.1; Appendix I.1). In addition, one dead loggerhead sea turtle, entangled in fishing gear, was sighted. Two species of sea turtles were identified including 17 hawksbill turtles and 2 loggerhead turtles. The remaining 10 sea turtles could not be identified. Of the 29 turtles seen, 21 or 72% were sighted during "useable" survey conditions (see Table 5.1). This excludes six turtle sightings during the "post seismic" period (90 s to 6 h after seismic operations had ceased), and two turtles sighted when the *Ewing* was traveling <3.7 km/h (Table 5.1). Analyses described below were limited to the 21 "useable" sightings, similar to cetacean analyses described in Chapter 4.

The single dead loggerhead sea turtle was seen 9 Feb. during seismic activities (Appendix I.1). The dead loggerhead was observed floating at the surface, its hind, right flipper entangled in fishing gear (a rope several meters long). The turtle appeared to have been dead for ~5 days, and it smelled of decomposition. The observers concluded that the turtle's death was due to fishing activities and did not implement a shut down. The Mexican authorities and NMFS were notified of this dead turtle on the day it was observed. As requested by the Mexican authorities, the dead turtle was retrieved by a member of the crew of the spotter vessel and brought to shore for inspection.

One third (7) of the 21 useable turtle sightings were made while seismic operations were underway, and 14 of the sightings occurred during non-seismic periods (Table 5.1). Ramp ups were postponed three times during the survey because of the presence of sea turtles. The airguns were powered down three times and shut down four times due to the presence of sea turtles within the 180 dB sound radius (Appendices I.1, I.2).

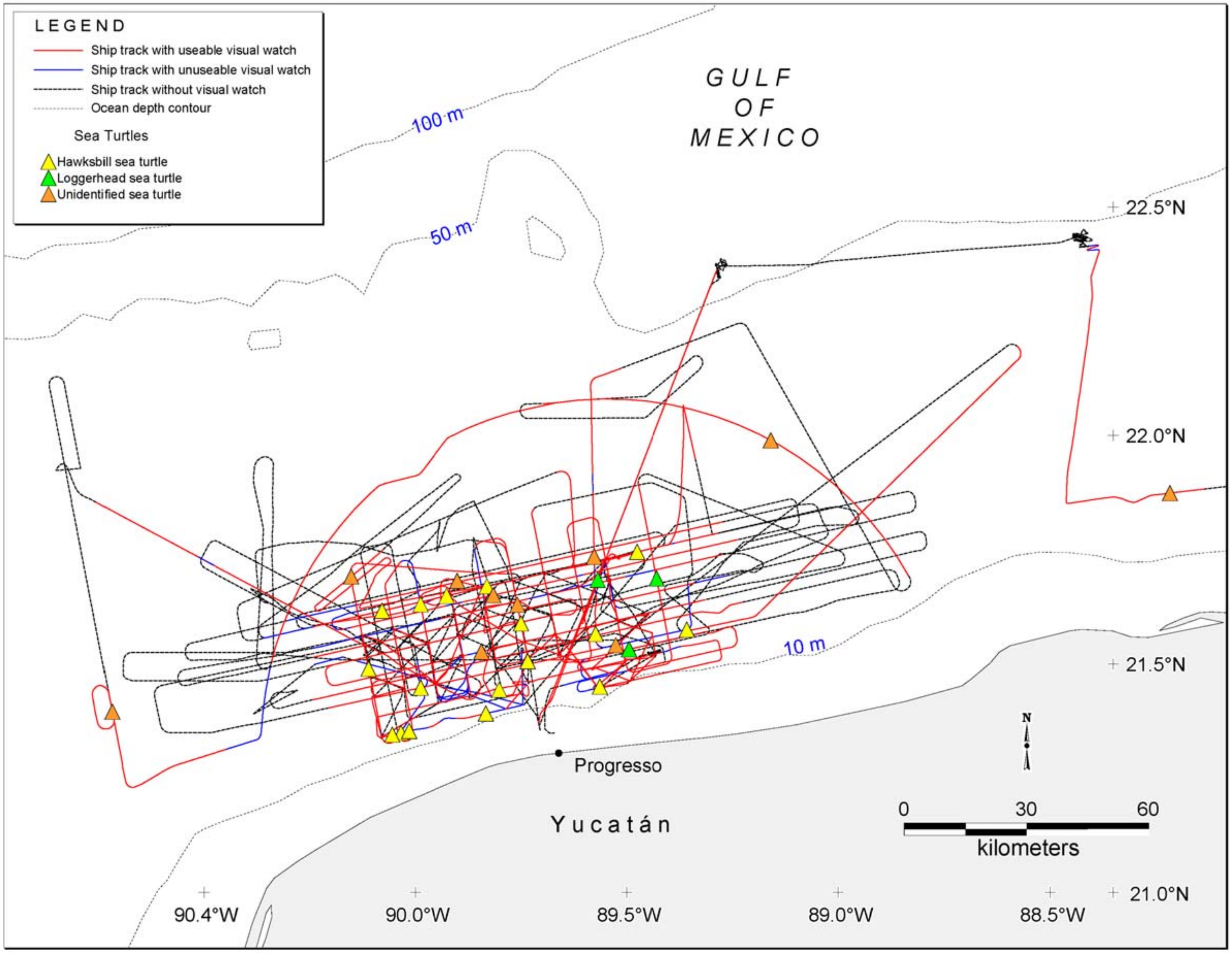

FIGURE 5.1. Locations of sea turtle sightings showing periods with useable vs. unuseable survey effort during the Chicxulub seismic cruise, 7 Jan.–20 Feb. 2005.

TABLE 5.1. Total number and number of useable[a] sea turtle sightings during seismic and non-seismic periods during the 7 Jan.–20 Feb. 2005 Chicxulub seismic cruise.

	Seismic		Non-seismic		Post-seismic		Total	
Turtle Species/Grouping	**Groups**	**Indiv.**	**Groups**	**Indiv.**	**Groups**	**Indiv.**	**Groups**	**Indiv.**
All Sightings								
Hawksbill sea turtle	4	4	9	9	4	4	17	17
Loggerhead sea turtle	0	0	2	2	0	0	2	2
Unidentified sea turtle	3	3	5	5	2	2	10	10
Total	**7**	**7**	**16**	**16**	**6**	**6**	**29**	**29**
Useable Sightings								
Hawksbill sea turtle	4	4	7	7	N/A	N/A	11	11
Loggerhead sea turtle	0	0	2	2	N/A	N/A	2	2
Unidentified sea turtle	3	3	5	5	N/A	N/A	8	8
Total	**7**	**7**	**14**	**14**	**N/A**	**N/A**	**21**	**21**

Note: N/A means not available.

[a] Useable sightings are those made during useable daylight periods of visual observation, as defined in *Acronyms and Abbreviations*. This table excludes one dead sea turtle seen during the cruise (see text).

Distribution

Hawksbills were the most frequently observed turtle during the Chicxulub seismic survey; they made up 89% of the turtles that were identified to species (Table 5.1). They were fairly evenly distributed throughout the survey area (Fig. 5.1). Given the year-round presence of feeding hawksbills in the shallow waters of the study area, it is not surprising that they were the most commonly seen turtle species.

Behavior

The following types of behavioral data were collected for all turtle sightings: closest observed point of approach to the array, movement, and behavior (Tables 5.2–5.4). The data described here are limited to “useable” turtle sightings.

Closest Observed Point of Approach.—On average, turtles were observed at similar distances from the airgun array when it was operating (mean 284 m, n = 7) and when the airguns were off (290 m, n = 14; Table 5.2). The standard deviations about these means were large for both the seismic and non-seismic sightings (Table 5.2).

Movement.—Of 21 “useable” turtle sightings for which the first movement was noted, 7 (or 33%) were seen while the airguns were operating (Table 5.3). During seismic operations, the most frequently observed type of movements were “none” (3) and “unknown” (3); one turtle was observed swimming away (Table 5.3). During non-seismic periods, again the most frequently observed movements were “none” (n = 7) and “unknown” (n = 5). A single turtle was observed swimming toward the vessel and another was seen swimming parallel during non-seismic periods.

Behavior.—Overall, most (n = 17 or 81%) of the 21 “useable” sea turtles were first observed logging, i.e., not actively moving relative to the ship; 35% of these 17 turtles were sighted during seismic operations (Table 5.4). Logging accounted for 86% of the 7 sightings during seismic seismic operations and 79% of the total 14 sightings during non-seismic conditions. Swimming was the only

TABLE 5.2. Closest observed points of approach (CPA) of turtles to the airgun array relative to airgun volume during the Chicxulub cruise, 7 Jan.–20 Feb. 2005. Data are shown for all turtle sightings during "seismic" and "non-seismic" periods, excluding the six turtles seen during the "post seismic" period. Useable[a] turtle sightings are also shown.

	Seismic					Non-seismic			
Sea Turtle Grouping	**Array Volume**	**Mean CPA (m)**	**s.d.**	***n***	**Range (m)**	**Mean CPA (m)**	**s.d.**	***n***	**Range (m)**
All Sightings									
	80	142	NA	1	142	-	-	-	-
	3005	1063	NA	1	1063	-	-	-	-
	6970	156	28	5	128-196	-	-	-	-
	All	**284**	**268**	**7**	**128-1063**	**274**	**395**	**16**	**89-1725**
Useable Sightings									
	80	142	NA	1	142	-	-	-	-
	3005	1063	NA	1	1063	-	-	-	-
	6970	156	28	5	128-196	-	-	-	-
	All	**284**	**268**	**7**	**128-1063**	**290**	**421**	**14**	**89-1725**

[a] Useable sightings are those made during useable daylight periods of visual observation, as defined in *Acronyms and Abbreviations.* This excludes one dead sea turtle (see text).

other behavior observed and recorded for sea turtles. Two loggerhead turtles were observed swimming during non-seismic periods.

Summary and Conclusions

The number of "useable" turtle sightings recorded from the *Ewing* (n = 21), and the low proportion of these sightings during seismic periods (n = 7), limits interpretation of behavior relative to seismic operations. Overall, sea turtles were observed at approximately the same mean distance from the airguns during seismic and non-seismic conditions: 284 m vs. 290 m, respectively. However, more sea turtles were observed during non-seismic periods, which may indicate that turtles were actively avoiding the vessel during seismic operations, or behaving in a way that made them less conspicuous. Most sea turtles seen during both seismic and non-seismic periods were logging at the surface with variable orientations when first observed, and did not display any apparent avoidance behavior. Only one of the seven turtles seen during seismic operations was actively moving away from the vessel.

A total of four shut downs and three power downs were implemented during the cruise because of sea turtles. All shut downs occurred when a turtle was first sighted within the 180 dB sound radius; there were no cases when a full shut down had been preceded by an initial power down. All seven of these turtle sightings were well within (<1100 m) the 180 dB safety radius of 3500 m during seismic operations in shallow water (<40 m); six of the seven turtles were seen <200 m from the operating airguns before the airguns were powered or shut down. Given these factors, all seven of the turtles first sighted within the safety radius likely would have received sound levels >180 dB before being seen if they had been diving recently. Ramp ups were delayed three times because of the proximity of sea turtles to the airguns.

In general, the small "useable" data set limits any certain conclusions regarding the effects of seismic operations on sea turtles from the Chicxulub seismic project.

TABLE 5.3. Comparison of direction of movement by sea turtle groups seen during non-seismic and seismic periods during the Chicxulub seismic cruise, 7 Jan.–20 Feb. 2005. All turtle sightings made during these periods and only useable[a] turtle sightings are shown.

	Direction of Movement - Seismic				Direction of Movement - Non-seismic					Total Seismic + Non-seismic
Grouping	**None**	**Away**	**Unknown**	**Total**	**None**	**Parallel**	**Toward**	**Unknown**	**Total**	
All Sightings[b]										
Hawksbill sea turtle	2	1	1	4	6	0	0	3	9	**13**
Loggerhead sea turtle	0	0	0	0	0	1	1	0	2	**2**
Unidentified sea turtle	1	0	2	3	2	0	0	3	5	**8**
Total	***3***	***1***	***3***	***7***	***8***	***1***	***1***	***6***	***16***	**23**
Useable Sightings										
Hawksbill sea turtle	2	1	1	4	5	0	0	2	7	**11**
Loggerhead sea turtle	0	0	0	0	0	1	1	0	2	**2**
Unidentified sea turtle	1		2	3	2	0	0	3	5	**8**
Total	***3***	***1***	***3***	***7***	***7***	***1***	***1***	***5***	***14***	**21**

[a] Useable sightings are those made during useable daylight periods of visual observation, as defined in *Acronyms and Abbreviations.* Excludes one dead sea turtle and 6 sea turtle groups seen during post-seismic periods.

[b] Excludes one dead loggerhead sea turtle and 6 sea turtle groups seen during post-seismic periods.

TABLE 5.4. First observed behavior by sea turtle groups during non-seismic and seismic periods during the Chicxulub cruise, 7 Jan.–20 Feb. 2005. All turtle sightings as well as only those that are useable are shown.

Grouping	First Observed Behavior - Seismic			First Observed Behavior - Non-seismic				Total Seismic + Non-seismic
	Log	Unk'n	Total	Log	Swim	Unk'n	Total	
All Sightings[a]								
Hawksbill sea turtle	4	0	4	8	1	0	9	**13**
Loggerhead sea turtle	0	0	0	0	2	0	2	**2**
Unidentified sea turtle	2	1	3	4	0	1	5	**8**
Total	***6***	***1***	***7***	***12***	***3***	***1***	***16***	**23**
Useable Sightings[b]								
Hawksbill sea turtle	4	0	4	7	0	0	7	**11**
Loggerhead sea turtle	0	0	0	0	2	0	2	**2**
Unidentified sea turtle	2	1	3	4	0	1	5	**8**
Total	***6***	***1***	***7***	***11***	***2***	***1***	***14***	**21**

[a] Excludes one dead loggerhead sea turtle and six sea turtle groups seen during post-seismic periods.

[b] Useable sightings are those made during useable daylight periods of visual observation, as defined in *Acronyms and Abbreviations.* Excludes one dead sea turtle and six sea turtle groups seen during post-seismic periods.

6. ACKNOWLEDGEMENTS

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7. LITERATURE CITED

Arenas, P., L. Sarti, and P. Ulloa. 2003. Sea turtle conservation and management in Mexico. Available at http://ola.icmyl.unam.mx/Tortugas

Barlow, J. and B. Taylor. 1998. Preliminary abundance of sperm whales in the northeastern temperate Pacific estimated from a combined visual and acoustic survey. Paper SC/50/CA WS20 presented to Intern. Whal. Comm., June 1998 (unpublished).

Barmes, T., K.L. Eckert and J. Sybesma. 1993. WIDECAST Sea Turtle Recovery Action Plan for Aruba. *In:* K.L. Eckert (ed.). CEP Tech. Rep. 25. UNEP Caribbean Environ. Progr., Kingston, Jamaica. 58 p.

Bjorndal, K.A. 1982. The consequences of herbivory for the life history pattern of the Caribbean green turtle, *Chelonia mydas*. p. 111-116 *In:* K.A. Bjorndal (ed.) Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, D.C.

Buckland, S.T., D. Bloch, K.L. Cattanach, T. Gunnlaugsson, K. Hoydal, S. Lens and J. Sigurjónsson. 1993. Distribution and abundance of long-finned pilot whales in the North Atlantic, estimated from NASS-1987 and NASS-89 data. **Rep. Int. Whal. Comm. Spec. Iss.** 14:33-50.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers and L. Thomas. 2001. Introduction to distance sampling/Estimating abundance of biological populations. Oxford Univ. Press, Oxford, U.K. 432 p.

Burgess, W.C. and C.R. Greene, Jr. 1999. Physical acoustics measurements. p. 3-1 to 3-63 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA22303. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. **The Leading Edge** 2000(8, Aug.): 898-902.

Carr, A., M.H. Carr and A.B. Meylan. 1978. The ecology and migrations of sea turtles. The west Caribbean green turtle colony. **Bull. Am. Mus. Nat. Hist.** 162(1):1-46.

Cattanach, K.L., J. Sigurjónsson, S.T. Buckland and T. Gunnlaugsson. 1993. Sei whale abundance in the North Atlantic, estimated from NASS-87 and NASS-89 data. **Rep. Int. Whal. Comm.** 43:315-321.

CITES. 2002. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Available at http://www.cites.org/

d'Auvergne, C. and K.L. Eckert. 1993. WIDECAST Sea Turtle Recovery Action Plan for St. Lucia. *In:* K.L. Eckert (ed.). CEP Technical Report No. 26. UNEP Caribbean Environ. Progr., Kingston, Jamaica. 70 p.

Davenport, J. and G.H. Balazs. 1991. 'Fiery bodies' - are pyrosomas an important component of the diet of leatherback turtles? **Brit. Herp. Soc. Bull.** 31:33-38.

Davis, R.W, W.E. Evans, J.C. Norris, B. Würsig, K.D. Mullin, D.C. Biggs, J.H. Wormuth and C.A. Ribic. 2000. Summary, conclusions and recommendations. Chapter 9 (p. 317-328) *In:* R.W. Davis, W.E. Evans and B. Würsig (eds.), Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: distribution, abundance and habitat associations, Vol. II: technical report. U.S. Dep. Interior, Geol. Surv., Biol. Resour. Div., USGS/BRD/CR-1999-0006 and Minerals Manage. Serv., OCS Study MMS 2000-003.

Earlham College. 2001. Biological Diversity 2001. Green turtle (*Chelonia mydas*) conservation. Available at http://www.earlham.edu/~breckme/green_sea_turtles.htm

EuroTurtle. 2001. Sea turtle outlines. Website. http://www.euroturtle.org

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. **J. Acoust. Soc. Am.** 111(6):2929-2940.

Fristrup, K. and C. Clark. 1997. Combining visual and acoustic survey data to enhance density estimation. **Rep. Intern. Whal. Commis.** 47: 933-936.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. **Mar. Technol. Soc. J.** 37(4):16-34.

Greene, C.R., Jr. and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. **J. Acoust. Soc. Am.** 83(6):2246-2254.

Greene, C.R., Jr., with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In*: W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr., R. Norman and J.S. Hanna. 1998. Physical acoustics measurements. p. 3-1 to 3-64 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of BP Exploration (Alaska)'s open-water seismic program in the Alaskan Beaufort Sea, 1997. LGL Rep. TA2150-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 318 p.

Gulick, S. 2005a. Seismic investigations of the Chicxulub impact crater. Preliminary cruise report, R/V *Maurice Ewing* cruise no. EW0501. Univ. of Texas Inst. for Geophysics, Austin, TX.

Gulick, S. 2005b. Preliminary report of cruise 0501 of the research vessel *Maurice Ewing* offshore Progreso, Yucatan, January 15 – Feburary 19, 2005. Prelim. rep. from Univ. of Texas Inst. for Geophysics, Austin, TX, for La Secretaria de Relaciones Exteriores, Mexico.

Haley, B., and W.R. Koski. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Northwest Atlantic Ocean, July–August 2004. LGL Rep. TA2822-27. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 80 p.

Harris, R.E., G.W. Miller and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17(4):795-812.

Hartog, J.C. den and M.M. van Nierop. 1984. A study of the gut contents of six leathery turtles, *Dermochelys coriacea* (Linnaeus) (Reptilia: Testudines: Dermochelyidae) from British waters and from the Netherlands. **Zool. Verh.** 209(1984):1-36.

Holbrook, W.S., P. Paramo, S. Pearse and R.W. Schmitt. 2003. Thermohaline fine structure in an oceanographic front from seismic reflection profiling. **Science** 301(5634):821-824.

Holst, M. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's TAG seismic study in the mid-Atlantic Ocean, October-November 2003. LGL Rep. TA2822-21. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 42 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November-December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 125 p.

Horrocks, J.A. 1992. WIDECAST Sea Turtle Recovery Action Plan for Barbados. *In:* K.L. Eckert (ed.). CEP Tech. Rep. 12. UNEP Caribbean Environ. Progr., Kingston, Jamaica. 61 p.

IUCN (The World Conservation Union). 2002. IUCN Red List of Threatened Species. http://www.iucn.org/themes/ssc/redlist2002/redlistlaunch.htm

IWC (International Whaling Commission). 2003. Whale population estimates. http://www.iwcoffice.org/Estimate.htm

Jefferson, T.A. and S K. Lynn. 1994. Marine mammal sightings in the Caribbean Sea and Gulf of Mexico, summer 1991. **Carib. J. Sci.** 30(1–2):83–89.

Jefferson, T.A. and A.J. Schiro. 1997. Distribution of cetaceans in the offshore Gulf of Mexico. **Mamm. Rev.** 27(1):27-50.

Koski, W.R., D.H. Thomson and W.J. Richardson. 1998. Descriptions of Marine Mammal Populations. p. 1-182 plus Appendices *In:* Point Mugu Sea Range Marine Mammal Technical Report. Rep. from LGL Ltd., King City, Ont., for Naval Air Warfare Center, Weapons Div., Point Mugu, CA, and Southwest Div. Naval Facilities Engin. Command, San Diego, CA. 322 p.

LGL Ltd. 2003a. Request by Lamont-Doherty Earth Observatory for an Incidental Harassment Authorization to allow the incidental take of marine mammals during a marine seismic survey off the northern Yucatán Peninsula, Gulf of Mexico, March–April 2004. LGL Rep. TA2822-14. Rep. from LGL Ltd, King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 84 p

LGL Ltd. 2003b. Environmental assessment of a marine seismic survey by the R/V *Maurice Ewing* off the northern Yucatán Peninsula, Gulf of Mexico, March–April 2004. LGL Rep. TA2822-15. Rep. from LGL Ltd, King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Sci. Found., Arlington, VA. 98 p.

Longhurst, A.R. 1998. Ecological geography of the sea. Academic Press, San Diego, CA. 398 p.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

MacLean, S.A. and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory’s seismic program in the Gulf of Alaska, August–September 2004. LGL Rep. TA2822-28. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p.

Manghi, M., C. Fossani, M. Priano, G. Pavan, J.F. Borsani and C. Bergamasco. 1999. Acoustic and visual methods in the odontocetes survey: a comparison in the Central Mediterranean Sea. p. 251-253 *In* P.G.H. Evans and E.C.M. Parson (eds.), European Cetaceans 12. Proc. 12th Annu. Conf. Europ. Cetac. Soc., Monaco, Monte Carlo. European Cetac. Soc., Valencia, Spain.

Márquez, M.R. 1990. Sea turtles of the world. An annotated and illustrated catalogue of sea turtle species known to date. FAO Fisheries Synopsis No. 125, Vol 11. Rome. 81 p. Available at http://www.sefsc.noaa.gov/seaturtlepublications.jsp.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe and J. Murdoch. 1998. The response of humpback whales (*Megaptera novangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. **APPEA (Austral. Petrol. Product. Explor. Assoc.) Journal** 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000. Marine seismic surveys: Analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, W.A., for Austral. Petrol. Prod. Assoc., Sydney, N.S.W. 188 p.

Meylan, A.B. 1999. International movements of immature and adult hawksbill turtles (*Eretmochelys imbricata*) in the Caribbean region. **Chelonian Conserv. Biol.** 3(2): 189-194.

Miller, J.D. 1997. Reproduction in sea turtles. p. 51-81 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Moore, S.E., M.E. Dahlheim, K.M. Stafford, C.G. Fox, H.W. Braham, M.A. McDonald and J. Thomason. 1999. Acoustic and visual detection of large whales in the Eastern North Pacific Ocean. NOAA Tech. Mem. NMFS-AFSC-107. 27 p.

Mullin, K.D. and W. Hoggard. 2000. Visual surveys of cetaceans and sea turtles from aircraft and ships. Chapter 4. p. 111-171 *In:* R.W. Davis, W.E. Evans and B. Würsig (eds.), Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: distribution, abundance and habitat associations, Vol. II: technical report. U.S. Dep. Interior, Geol. Surv., Biol. Resour. Div., USGS/BRD/CR-1999-0006 and Minerals Manage. Serv., OCS Study MMS 2000-003.

NMFS. 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. **Fed. Regist.** 60(200, 17 Oct.):53753-53760.

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California/Notice of receipt of application. **Fed. Regist.** 65(60, 28 Mar.):16374-16379.

NMFS. 2003. Small takes of marine mammals incidental to specified activities; oceanographic surveys off the northern Yucatan Peninsula in the Gulf of Mexico/Notice of receipt of application… **Fed. Regist.** 68(241, 16 Dec.):70000-70005.

NMFS. 2004. Small takes of marine mammals incidental to specified activities; oceanographic surveys off the northern Yucatan Peninsula in the Gulf of Mexico/Notice of issuance of an incidental take authorization. **Fed. Regist.** 69(60, 29 Mar.):16233-16240.

Norris, T.F., M.M. McDonald and J. Barlow. 1999. Acoustic detections of singing humpback whales in the eastern North Pacific during their northbound migration**. J. Acoust. Soc. Am**. 106(1):506-514.

Ortega-Ortiz, J.G. 2002. Multiscale analysis of cetacean distribution in the Gulf of Mexico. Ph.D. Thesis. Texas A&M Univ., College Station, TX. 170 p.

Pavan, G. 2005. Cruise RV *Ewing* EW0412 LDEO / Columbia Univ., results, comments and recommendations. Rep. from Univ. degli Studi di Pavia, Centro Interdisciplinare di Bioacustica e Ricerche Ambientali. Pavia, Italy, March 15, 2005.

Rawson, M. 2005. Aerial surveys off the north coast of Yucatán in the Chicxulub Basin in support of the research project Levantamiento Sismico Marine del Navio de Investigaciones *Maurice Ewing* Fuera de la Costa Septentrional de Yucatan, Golfo de México. May 2005. Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY. 33 p.

Reeves, R.R., B.S. Stewart, P.J. Clapham and J.A. Powell. 2002. Guide to Marine Mammals of the World. Chanticleer Press, New York, NY.

Reyes, J.C. 1991. The conservation of small cetaceans: a review. Report prepared for the Secretariat of the Convention on the Conservation of Migratory Species of Wild Animals. UNEP/CMS Secretariat, Bonn.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego. 576 p.

Sea Turtle Survival League. 1995a. Basic biology, nesting sites, and range of the green sea turtle. http://cccturtle.org/green.htm

Sea Turtle Survival League. 1995b. Basic biology, nesting sites, and range of the hawksbill sea turtle. http://cccturtle.org/hawksbill.htm

Sea Turtle Survival League. 1995c. Basic biology, nesting sites, and range of the loggerhead sea turtle. http://cccturtle.org/logger.htm

Sea Turtle Survival League. 1995d. Basic biology, nesting sites, and range of the Kemp's ridley sea turtle. http://cccturtle.org/kemps.htm

Sea Turtle Survival League. 1995e. Basic biology, nesting sites, and range of the leatherback sea turtle. http://cccturtle.org/leather.htm

Sea Turtle Survival League. 1998. Development threatens major Mexican nesting beach at X'cacel. http://www.cccturtle.org/a_xcacel.htm

Seal Conservation Society. 2001. Pinniped species information pages. Available at http://www.pinnipeds.org/species/species.htm

SEAMAP. 2003. Cetacean monitoring system marine mammal detection and tracking technical overview. Document No. 10-32-0010, Rev. 3.0, Seamap Pte, Ltd., Singapore.

Smith, T.D., J. Allen, P.J. Clapham, P.S. Hammond, S. Katona, F. Larsen, J. Lien, D. Mattila, P. Palsbøll, J. Sigurjónsson, P.T. Stevick and N. Øien. 1999. An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Megaptera novaeangliae*). **Mar. Mamm. Sci.** 15(1):1-32.

Smultea, M.A. and M. Holst. 2003. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Hess Deep area of the Eastern Equatorial Tropical Pacific, July 2003. LGL Rep. TA2822-16. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 68 p.

Smultea, M.A., M. Holst, et al. 2003. Marine mammal monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. LGL Rep. TA2822-12. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

Smultea, M.A., M. Holst, W.R. Koski and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April–June 2004. LGL Rep. TA2822-26. Rep. From LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Smultea, M.A., W.R. Koski and T.J. Norris. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's marine seismic study of the Blanco Fracture Zone in the Northeastern Pacific Ocean, October-November 2004. LGL Rep. TA2822-29. Rep. From LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 89 p.

Stafford, K.M., C.G. Fox and D.S. Clark. 1998. Long-range acoustic detection and localization of blue whale calls in the Northeast Pacific Ocean**. J. Acoust. Soc. Am.** 104(6):3616-3625.

Stafford, K. M., S. L. Nieukirk, and C. G. Fox. 1999. An acoustic link between blue whales in the eastern tropical Pacific and the Northeast Pacific. **Mar. Mamm. Sci**. 15(4):1258-1268.

Stienessen, S.C. 1998. Diel, seasonal, and species-specific trends in vocalizations of dolphins in the Gulf of Mexico. M.S. thesis, Texas A&M Univ., College Station, TX. 72 p.

Stoltz, S.H., H. Goldstein, J. Beland, M.A. Smultea and T. Norris. 2004. Passive acoustic monitoring (PAM) handbook for marine mammal acoustic monitoring aboard the R/V *Maurice Ewin*g: PAM goals, SEAMAP operations instructions, and acoustic data collection protocol. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY.

Stevick, P.T., J. Allen, P.J. Clapham, N. Friday, S.K. Katona, F. Larsen, J. Lien, D.K. Mattila, P.J. Palsbøll, R. Sears, J. Sigurjónsson, T.D. Smith, G. Vikingsson, J. Øien, and P.S. Hammond. 2001. Trends in abundance of North Atlantic humpback whales, 1979-1993. Paper SC/53/NAH2 presented to the International Whaling Commission Scientific Committee.

Stevick, P.T., J. Allen, P.J. Clapham, N. Friday, S.K. Katona, F.Larsen, J. Lien, D.K. Mattila, P.J. Palsbøll, J. Sigurjónsson, T.D. Smith, N. Øien and P.S. Hammond. 2003. North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. **Mar. Ecol. Prog. Ser.** 258:263-273.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Report 323. Joint Nature Conservancy, Aberdeen , Scotland. 43 p.

Sybesma, J. 1992. WIDECAST Sea Turtle Recovery Action Plan for the Netherlands Antilles. *In:* K.L. Eckert (ed.). CEP Technical Report No. 11. UNEP Caribbean Environment Program, Kingston, Jamaica. 63 p.

Thomas J.A., S.A. Fisher and L.M. Ferm. 1986. Acoustic detection of cetaceans using a towed array of hydrophones. **Rep. Intern. Whal. Commis. (Spec. Iss.)** 8:139-148

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In:* W.J. Richardson (ed.), Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. Revised ed. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. (Advance copy).

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohenstiehl, E. Chapp, R.C. Holmes and M. Rawson. 2004b. Broad-band calibration of R/V Knorr seismic sources. **Geophys. Res. Lett.** 31:L14310.

UNEP. 1993. Sea Turtle Recovery Action Plan for St. Vincent and the Grenadines. CEP Technical Report No. 27. UNEP Caribbean Environment Program, Kingston, Jamaica.

U.S. Fish and Wildlife Service. 2003. Loggerhead Sea Turtle (*Caretta caretta*). U.S. Fish & Wildlife Service, North Florida Field Office. Available at http://ecos.fws.gov/i/C1T.html Accessed Sept. 2003

Waring, G.T., Quintal, J.M. and Swartz, S.L. (eds.) 2001. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2001. NOAA Tech. Memo. NMFS-NE-168. 307 p.

Waring, G.T., Quintal, J.M. and Fairfield, C.P. (eds.) 2002. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 2002. NOAA Tech. Memo. NMFS-NE-169. 318 p.

Whitehead, H. 2002. Estimates of the current global population size and historical trajectory for sperm whales. **Mar. Ecol. Prog. Ser.** 242:295-304.

Würsig, B., T.A. Jefferson and D.J. Schmidly. 2000. The marine mammals of the Gulf of Mexico. Texas A&M Univ. Press, College Station, TX. 232 p.

APPENDIX A:[1]

Incidental Harassment Authorization Issued to L-DEO for the Seismic Study off the Northern Yucatan Peninsula in the Gulf of Mexico

DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE

Incidental Harassment Authorization

Lamont-Doherty Earth Observatory, Columbia University, P.O. Box 1000, 61 Route 9W, Palisades, New York 10964-8000, is hereby authorized under section 101(a)(5)(D) of the Marine Mammal Protection Act (16 U.S.C. 1371 (a)(5)(D)) and 50 CFR 216.107, to harass a small number of marine mammals incidental to conducting two[2] marine seismic surveys off of the northern Yucatan Peninsula in the Gulf of Mexico, contingent upon the following conditions:

1. This Authorization is valid from February 27, 2004 through February 26, 2005.

2. This Authorization is valid only for activities associated with conducting the seismic survey off the northern Yucatan Peninsula from the *R/V Maurice Ewing*.

3. (a) The taking, by incidental harassment only, is limited to the species listed under condition 3(b) below. The taking by serious injury or death of these species or the taking by harassment, injury or death of any other species of marine mammals is prohibited and may result in the modification, suspension or revocation of this Authorization.

(b) The species authorized for incidental harassment takings are: the sperm whale (*Physeter macrocephalus*), pygmy sperm whale (*Kogia breviceps*), dwarf sperm whale (*Kogia sima*), Cuvier's beaked whale (*Ziphius cavirostris*), Sowerby's beaked whale (*Mesoplodon densirostris*)[3], Gervais' beaked whale (*Mesoplodon europaeus*), Blainville's beaked whale (*Mesoplodon densirostris*), rough-toothed dolphin (*Steno bredanensis*), bottlenose dolphin (*Tursiops truncatus*), pantropical spotted dolphin (*Stenella attenuata*), Atlantic spotted dolphin (*Stenella frontalis*), spinner dolphin (*Stenella longirostris*), clymene dolphin (*Stenella clymene*), striped dolphin (*Stenella coeruleoalba*), short-beaked common dolphin (*Delphinus delphis*), long-beaked common dolphin (*Delphinus capensis*), Fraser's dolphin (*Lagenodelphis hosei*), Risso's dolphin (*Grampus griseus*), melon-headed whale (*Peponocephala electra*), pygmy killer whale (*Feresa attenuata*), false killer whale (*Pseudorca crassidens*), killer whale (*Orcinus orca*), short-finned pilot whale (*Globicephala macrorhynchus*), long-finned pilot whale (*Globicephala melas*), North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), minke whale (*Balaenoptera acutorostrata*), Bryde's whale (*Balaenoptera edeni*), sei

[1] This is a verbatim copy (retyped) of the IHA.
[2] Only one seismic survey was planned.
[3] The latin name for Sowerby's beaked whale should be *M. bidens*.

whale (*Balaenoptera borealis*), fin whale (*Balaenoptera physalus*), blue whale (*Balaenoptera musculus*) and hooded seal (*Cystophora cristata*).

(c) The authorization for taking by harassment is limited to the following acoustic sources without an amendment to this Authorization:

(1) A seismic airgun array with no more than 20 airguns operating on *R/V Maurice Ewing*;
(2) A multi-beam bathymetric sonar; and
(3) A sub-bottom profiler.

(d) The taking of any marine mammal in a manner prohibited under this Authorization must be reported within 48 hours of the taking to the Chief of the Permits Conservation Division, Office of Protected Resources, National Marine Fisheries Service, at (301) 713-2322, ext. 101.

4. The holder of this Authorization is required to cooperate with the National Marine Fisheries Service and any other Federal, state or local agency monitoring the impacts of the activity on marine mammals. The holder must notify the Chief of the Marine Mammal Conservation Division at least 48 hours prior to starting the seismic survey (unless constrained by the date of issuance of this Authorization in which case notification shall be made as soon as possible).

5. <u>Mitigation</u>. The holder of this authorization is required to:

(a) Use the measured sound pressure fields for the 20-gun array in relation to distance and direction from the airguns which predicts that the 180-dB distance from the airgun array will be 3500 m (11483 ft).

(b) Immediately power-down the seismic airgun array and/or other acoustic sources, whenever any marine mammals or sea turtles are sighted approaching close to or within the area delineated by the 180 dB (re 1 μPa_{rms}) isopleth as established under condition 5(a) for the authorized seismic source.

(c) Not proceed with powering up the seismic airgun array unless the safety zone described in condition 5(a) is visible and no marine mammals or sea turtles are detected within the appropriate safety zones; or until 15 minutes (for small odontocetes and pinnipeds) or 30 minutes (for mysticetes/large odontocetes) after there has been no further visual detection of the mammal(s) within the safety zone and the trained marine mammal observer on duty is confident that no marine mammals or sea turtles remain within the appropriate safety zone.

(d) Prior to commencing ramp-up described in condition 5(f), conduct a 30-minute period of observation by at least one trained marine mammal observer (1) at the commencement of seismic operations and (2) at any time electrical power to the airgun array is discontinued for a period of 1 hour or more.

(e) If the complete safety radii are not visible for at least 30 minutes prior to ramp-up in either daylight or nighttime, not commence ramp-up unless the seismic source has maintained an SPL of at least 180 dB during the interruption of seismic survey operations.

(f) If no marine mammals or sea turtles have been observed while undertaking mitigation condition 5(c), 5(d) and 5 (e), ramp-up airgun arrays no greater than 6 dB per 5-minutes until operating levels are reached: (1) At the commencement of seismic operations, and (2) anytime after the array has been powered down for more than 8 minutes or more when the vessel speed is 4 knots, for 6 minutes or more when the vessel speed is 5 knots, or for 10 minutes when the vessel speed is 3 knots or less, by commencing with the smallest airgun first and then adding additional guns in sequence until the full array is firing.

(g) If airguns are ramped-up at night, two observers, using night vision devices, will monitor for marine mammals within the safety radii, which must be visible, for 30 minutes prior to beginning and during, ramp-up procedures.

(h) To the extent practical, whenever a marine mammal or sea turtle is detected outside the safety radius, and based on its position and motion relative to the ship track is likely to enter the safety radius, an alternative ship speed or track will be calculated and implemented.

(i) Emergency shut-down. If observations are made or credible reports are received that one or more marine mammals of any species are within the area of this activity in an injured or mortal state, or are indicating acute distress, the seismic airgun array will be immediately shut down and the Chief of the Marine Mammal Conservation Division or a staff member contacted.

(k) Passive acoustic monitoring will be used whenever possible and marine mammal vocalization detections will be provided to the marine mammal observers immediately in order for them to verify presence.

6. Monitoring

(a) The holder of this Authorization must designate at least 4 marine mammal observers, at least two of whom are biologically-trained, on-site individuals, approved in advance by the National Marine Fisheries Service, to conduct the monitoring under this Authorization and to record the effects of seismic surveys and the resulting noise on marine mammals and sea turtles.

(b) Monitoring is to be conducted by the biological observer(s) described in condition 6(a) above, onboard the active seismic vessel. The observer(s) must be on active watch whenever the seismic array is operating during all daylight hours and, where possible, two observers whenever either of the seismic arrays are being powered up to (a) ensure that no marine mammals enter the appropriate safety zone whenever the seismic array is on, and (b) to record marine mammal and sea turtle activity as described in condition 6(f) below.

(c) To the extent possible, observers will be on watch for continuous periods of 4 hours or less.

(d) At all times, the crew must be instructed to keep watch for marine mammals. If any are sighted, the bridge watch-stander must immediately notify the biological observer. If a marine mammal is within, or closely approaching its designated safety zone, the source must be immediately powered down.

(e) Observations by the biological observers described in condition 6(a) above on marine mammal presence and activity will begin a minimum of 30 minutes prior to the estimated time that the seismic source is to be turned on and/or ramped-up.

(f) Monitoring will consist of noting: (*i*) the species, group size, age/size/sex categories (if determinable), the general behavioral activity, heading (if consistent), bearing and distance from seismic vessel, sighting cue, behavioral pace, and apparent reaction of all marine mammals and sea turtles seen to the seismic vessel and/or its airgun array (e.g., none, avoidance, approach, paralleling, etc) and; (*ii*) the time, location, heading, speed, and activity of the vessel (shooting or not), along with sea state, visibility, cloud cover and sun glare at (1) any time a marine mammal or sea turtle is sighted, (2) at the start and end of each watch, and (3) during a watch (whenever there is a change in one or more variables); and, (*iii*) the identification of all vessels that are visible within 5 km of the seismic vessel whenever a marine mammal is sighted, and the time observed, bearing, distance, heading, speed and activity of the other vessel(s).

(g) Biological observers will also conduct monitoring onboard the *R/V Maurice Ewing* while the seismic array is being deployed or being pulled from the water.

(h) All biological observers must be provided with and use appropriate night-vision devices, Big Eyes, and reticulated and/or laser range finding binoculars.

7. Reporting

(a) A draft report will be submitted to the National Marine Fisheries Service within 90 days after the end of the seismic survey off the northern Yucatan Peninsula in the Gulf of Mexico. The report will describe in detail (1) the operations that were conducted, (2) the marine mammals and sea turtles that were detected near the operations, (3) to the extent possible the results of the acoustical measurements to verify the safety radii[4], and (4) the methods, results, and interpretation pertaining to all monitoring tasks, a summary of the dates and locations of seismic operations, sound measurement data, marine mammal, and sea turtle sightings (dates, times, locations, activities, associated seismic survey activities), and estimates of the amount and nature of potential take of marine mammals by harassment or in other ways.

(b) The 90-day draft report will be subject to review and comment by the National Marine Fisheries Service. Any recommendations made by the National Marine Fisheries Service must be addressed in the final report prior to acceptance by the National Marine Fisheries Service. The draft report will be considered the final report for this activity under this Authorization if the National Marine Fisheries Service has not provided comments and recommendations within 60 days of receipt of the draft report.

[4] This acoustic measurement task was done during an earlier cruise in the northern Gulf of Mexico (Tolstoy et al. 2004a,b) and was not planned or conducted during this cruise.

8. Activities related to the monitoring described in this Authorization do not require a separate scientific research permit issued under section 104 of the Marine Mammal Protection Act.

9. A copy of this Authorization must be in the possession of the operator of the vessel operating under the authority of this Incidental Harassment Authorization.

APPENDIX B:
DEVELOPMENT AND IMPLEMENTATION OF SAFETY RADII

This appendix provides additional background information on the development and implementation of safety radii as relevant to the L-DEO seismic study discussed in this report. Additional information on L-DEO's calibration study conducted with various configurations of the *Ewing*'s airgun arrays is also provided. Further information on these topics can be found in Smultea et al. (2003) and Tolstoy (2004a,b).

It is not known whether exposure to a sequence of strong pulses of low-frequency underwater sound from marine seismic exploration actually can cause hearing impairment or non-auditory injuries in marine mammals (Richardson et al. 1995:372*ff*; Finneran et al. 2002). There has been considerable speculation about the potential for injury to marine mammals, based primarily on what is known about hearing impairment to humans and other terrestrial mammals exposed to impulsive low-frequency airborne sounds (e.g., artillery noise). The 180-dB criterion for cetaceans was established by NMFS (1995) based on those considerations, before any data were available on temporary threshold shift (TTS) in marine mammals. NMFS (1995, 2000) concluded that there are unlikely to be any physically-injurious effects on cetaceans exposed to received levels of seismic pulses up to 180 dB re 1 μPa root-mean-square (rms). The corresponding NMFS criterion for pinnipeds is 190 dB re 1 μPa (rms).

Finneran et al. (2002) have found that the onset of mild TTS in a beluga whale (odontocete) exposed to a single watergun pulse occurred at a received level of 226 dB re 1 μPa pk-pk and a total energy flux density of 186 dB re 1 $\mu Pa^2 \cdot s$. The corresponding rms value for TTS onset upon exposure to a single watergun pulse would be intermediate between these values. It is assumed (though data are lacking) that TTS onset would occur at lower received levels if the animals received a series of pulses. However, no specific results confirming this are available yet. On the other hand, the levels necessary to cause injury would exceed, by an uncertain degree, the levels eliciting TTS onset.

The above-mentioned 180 dB re 1 μPa level is measured on an rms basis. The rms pressure is an average over the seismic pulse duration of the seismic pulse (Greene 1997; Greene et al. 1998). This is the measure commonly used in recent studies of marine mammal reactions to airgun sounds. The rms level of a seismic pulse is typically about 10 dB less than its peak level (Greene 1997; McCauley et al. 1998, 2000a). Rms level is affected by duration of the received pulse, which depends on propagation effects between the source and the receiving animal. The greater the temporal dispersion of (i.e., the longer) the received pulse, the lower the expected rms level. Biological effects probably are more closely related to energy content of the received pulse than to its rms pressure, but we consider rms pressure because current NMFS criteria are based on that method.

Radii within which received levels were expected to diminish to various values relevant to NMFS criteria mentioned above were determined by L-DEO based on a combination of acoustic modeling and empirical measurements. Empirical data were obtained by Tolstoy et al. (2004a,b) for sounds from two 105 in^3 GI (generator injector) guns, a 20-airgun array (the largest array deployed from the *Ewing*), and various intermediate-sized airgun arrays. (The 20-airgun array used in the calibration study had a slightly larger total volume [8600 in^3] than the 20-airgun array [volume 6970 in^3] used in the Jan.-Feb. 2005 Chicxulub study.) The empirical data were collected in the Gulf of Mexico from 27 May to 3 Jun. 2003, with separate measurements in deep and shallow water (Tolstoy et al. 2004a,b).

The rms received levels in the near field around various airgun configurations used by L-DEO have also been predicted using a model. Figure B.1 shows the predicted sound field for a 20-airgun

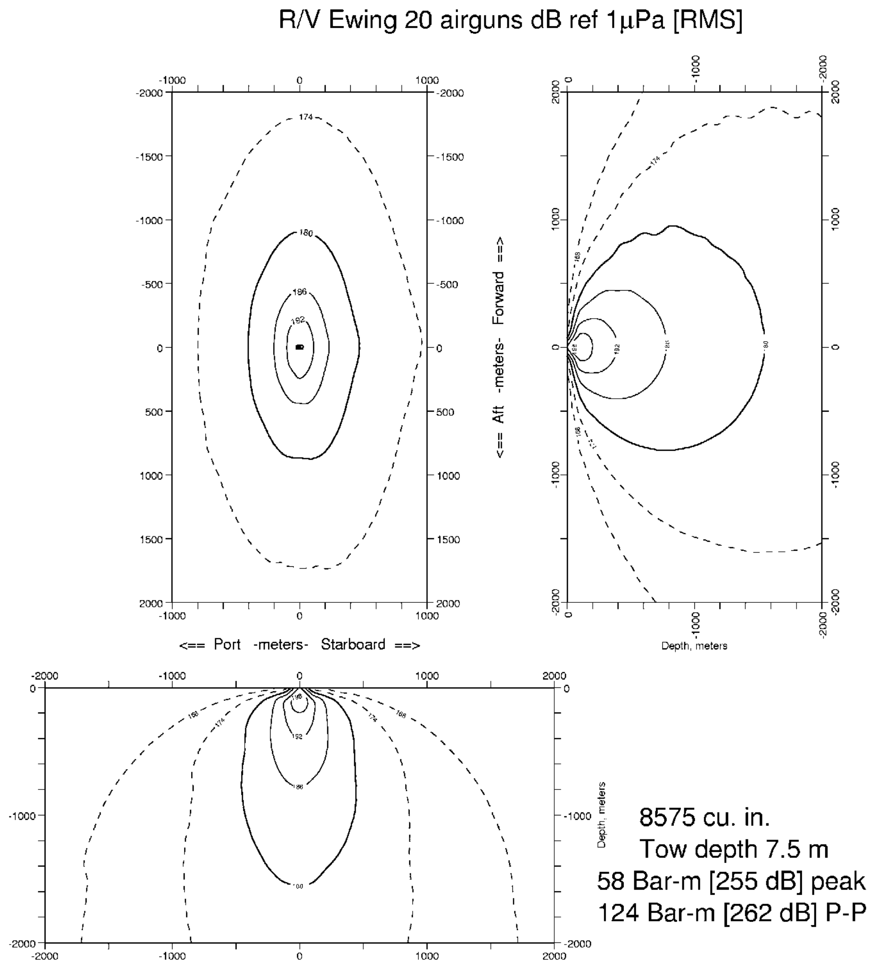

FIGURE B.1. Modeled received sound levels from the 8600 in^3 20-airgun array used for L-DEO's acoustic calibration study during late spring 2003 in the northern Gulf of Mexico. The 20-airgun array used during the Jan.–Feb. 2005 Chicxulub study conducted off the northern Yucatán Peninsula in the southern Gulf of Mexico had a different airgun configuration and a smaller total volume of 6970 in^3.

array with a volume 8600 in^3, on which the safety radii for the Chicxulub study were based. Figure B.2 shows the predicted sound fields for the 6947 in^3 20-airgun array used during L-DEO's 2004 SE Caribbean seismic survey, which had nearly the same volume as the 20-airgun array used for the Chicxulub survey (6970 in^3). The sound fields shown in Figures B.1 and B.2 pertain primarily to deep water, and the model does not allow for bottom interactions; however, all seismic operations during the Chicxulub study occurred in shallow (<100 m) water.

For mitigation purposes during L-DEO studies, three strata of water depth are distinguished: shallow (<100 m), intermediate (100–1000 m), and deep (>1000 m). The calibration study showed that sounds from L-DEO's larger airgun sources (i.e., 6–20 airguns) operating in deep water tended to have lower received levels than estimated by the model. In other words, the model tends to overestimate the actual distances at various sound levels in deep water (Tolstoy et al. 2004a,b). Conversely, in shallow water, the model substantially underestimates the actual measured radii for various source configurations ranging from 2 to 20 airguns. More specifically, the primary conclusions of L-DEO's calibration study relevant to this and other recent projects are summarized below:

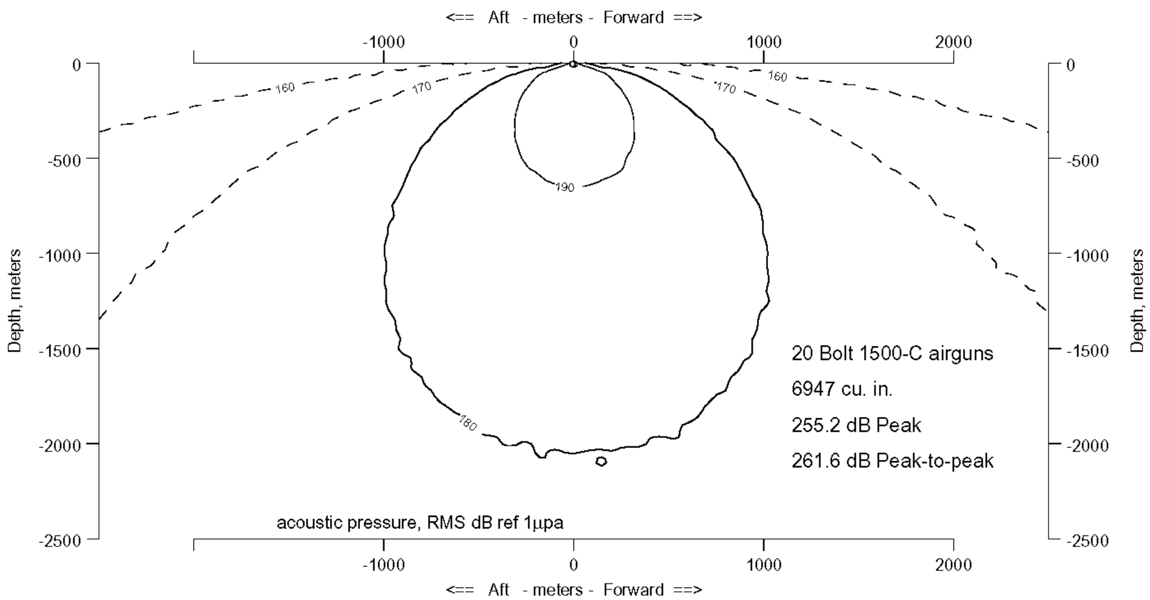

FIGURE B.2. Predicted received sound levels in deep water (along the fore–aft axis) from the 6947 in^3 20-airgun array used during L-DEO's seismic survey in the SE Caribbean Sea and adjacent Atlantic Ocean during Apr.–May 2004. This 6947 in^3 20-airgun array is very similar to the 6970 in^3 20-airgun array used during L-DEO's Jan.–Feb. 2005 Chicxulub seismic cruise off the northern Yucatán Peninsula. However, during the Chicxulub cruise, all seismic operations occurred in shallow water (<100 m) rather than the deep water assumed in deriving this Figure.

- For ***shallow*** water (<100 m deep), the 20-airgun radii shown in Table 3.1 are based on the empirical data of Tolstoy et al. (2004a,b) for 160, 170 and 180 dB, and are extrapolated to estimate the radius for 190 dB. No allowance was made for the fact that the 20-airgun airgun array used in this project was slightly smaller than that whose sounds were measured by Tolstoy et al. No empirical data were available for the single 80 in^3 airgun operating in shallow water that operated during the power-down procedure during this project; its radii in shallow water were assumed to be 3× those calculated by the L-DEO model for deep water.
- Empirical measurements were not conducted for ***intermediate depths*** (100–1000 m). On the expectation that results would be intermediate between those from shallow and deep water, a 1.5× correction factor has been applied to the estimates provided by the model for deep water situations. This is the same factor that was applied to all the model estimates during L-DEO cruises in 2003 and to the estimates for intermediate-depth water during all 2004 cruises.
- The empirical data indicated that, for ***deep water*** (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004a,b). Pending acquisition of additional empirical data, the estimated radii during airgun operations in deep water during all recent L-DEO cruises were predicted by L-DEO's model. However, the array did not operate in deep water during the Chicxulub study.

For sea turtles, NMFS specified a 180-dB radius for the project (Appendix A). This was the same safety radius applied for sea turtles during both L-DEO's spring 2004 SE Caribbean seismic survey and fall 2004 Blanco survey conducted from the *Ewing* (Smultea et al. 2004, 2005).

APPENDIX C: DESCRIPTION OF R/V *MAURICE EWING* AND EQUIPMENT USED DURING THE PROJECT

This appendix provides a detailed description of the standard equipment used during this and previous L-DEO seismic studies aboard the R/V *Maurice Ewing*

R/V Maurice Ewing *Vessel Specifications*

L-DEO used the R/V *Maurice Ewing* for the seismic study to tow the airgun array and hydrophone streamer (Fig. C.1, C.2). The *Ewing* was self-contained, with the crew living aboard the vessel. The *Ewing* has a length of 70 m (230 ft), a beam of 14.1 m (46.3 ft), and a draft of 4.4 m (14.4 ft). The *Ewing* has four 1000-kW diesel generators that supply power to the ship. The ship is powered by four 800-hp electric motors that, in combination, drive a single 5-blade propeller in a Kort nozzle and a single-tunnel electric bow thruster rated at 500 hp. At the typical operation speed of 7.4–9.3 km/h (4–5 knots) during seismic acquisition, the shaft rotation speed is about 90 rpm. When not towing seismic survey gear, the *Ewing* cruises at 18.5–20.4 km/h (10–11 knots) and has a maximum speed of 25 km/h (13.5 knots). It has a normal operating range of about 31,500 km (17,000 n.mi.). The maneuverability of the vessel was limited during operations, due to the presence of the streamer and airgun array behind the vessel.

Other details of the *Ewing* include the following:

Owner:	National Science Foundation
Operator:	Lamont-Doherty Earth Observatory of Columbia University
Flag:	United States of America
Date Built:	1983 (modified in 1990)
Gross Tonnage:	1978
Fathometers:	3.5 and 12 kHz hull-mounted transducers; Furuno FGG80 echosounder; Furuno FCU66 echosounder recorder
Bottom Mapping Equipment:	Atlas Hydrosweep DS-2, 15.5 kHz multibeam bathymetric sonar: details below
Compressors for Airguns:	LMF DC, capable of 1000 standard cubic feet per minute (scfm) at 2000 psi
Accommodation Capacity:	21 crew plus 3 technicians and 26 scientists

The *Ewing* also served as a platform from which vessel-based MMOs watched for marine mammals and sea turtles. The flying bridge was the best vantage point and afforded good visibility for the observers (Fig. C.1). However, visibility immediately astern of the *Ewing* was slightly restricted because of intervening superstructures (Fig. C.3, C.4). L-DEO constructed an MMO station with an overhead structural canopy on the flying bridge for shelter from sun, wind, and rain (Fig. C.5).

FIGURE C.1. The source vessel, the R/V *Maurice Ewing,* showing the location of the flying bridge from which visual observations were made by the marine mammal and sea turtle observers.

FIGURE C.2. The R/V *Maurice Ewing* towing a 20-airgun array during L-DEO's spring 2004 SE Caribbean seismic survey. This array configuration was similar to that used during the Jan.–Feb. 2005 Chicxulub seismic study off the northern Yucatán Peninsula in the southern Gulf of Mexico. Each airgun is suspended from an orange air-filled float seen floating at the water surface off the vessel's stern. The airgun lines are towed from the two black transverse booms seen in this photo (Photo by G. Christeson, University of Texas Institute of Geophysics).

filename:StarboardProfile&AfterSection(revised)

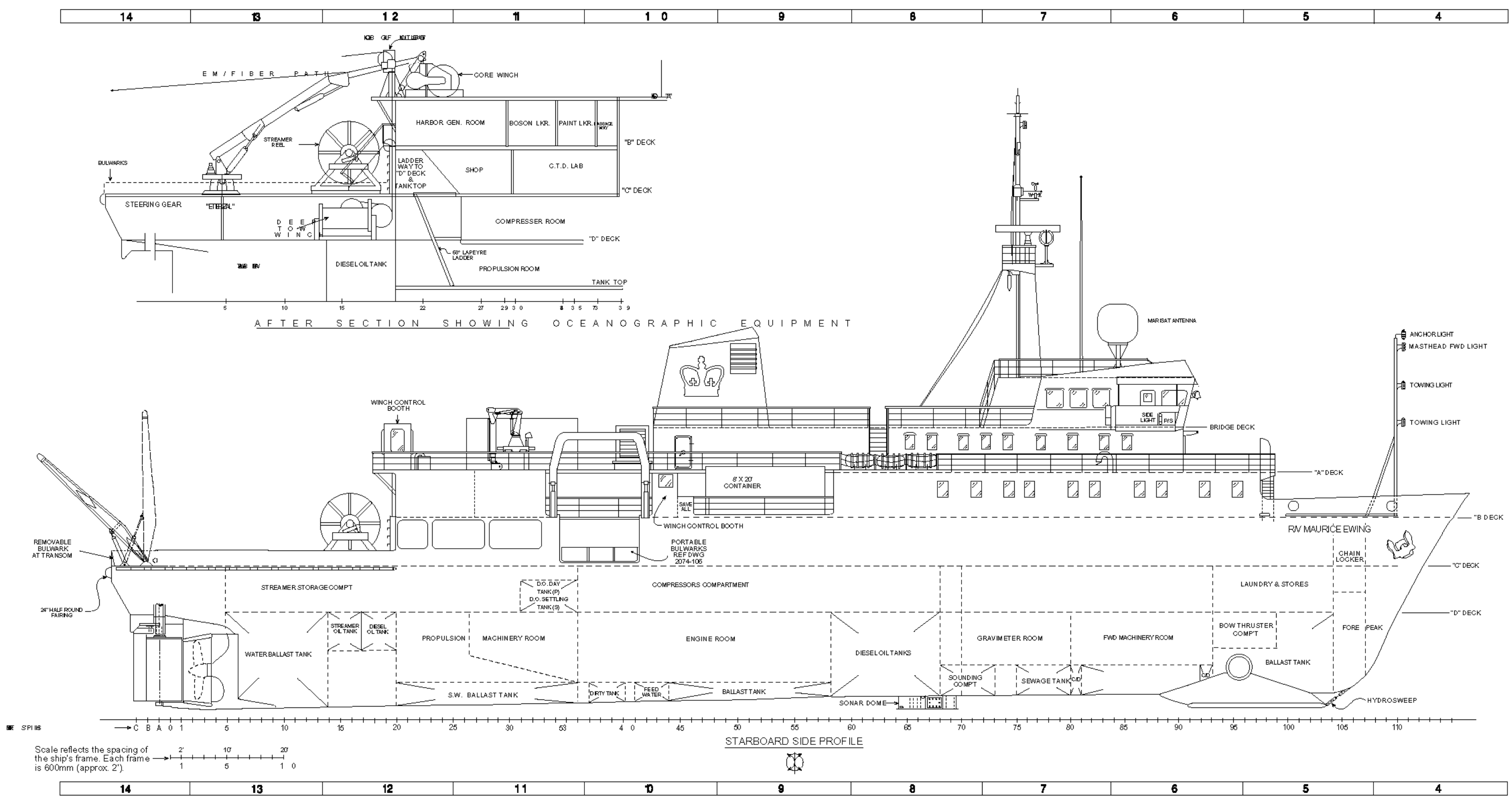

FIGURE C.3. Schematic starboard profile of the R/V *Maurice Ewing*.

FIGURE C.4. A view looking toward the stern from the center of the visual observer station on the flying bridge of the *Ewing*, showing the ship structures (two support structures and, at center, a smokestack) that partially block the view to the stern. The partial obstruction is considerably reduced when two observers are stationed on opposite sides of the flying bridge.

FIGURE C.5. A view of the flying bridge of the *Ewing* showing the visual observer station and associated equipment, including two mounted 25x150 "Big-eye" binoculars used during the study.

Multibeam Sonar, Sub-bottom Profiler, and Echosounder

Along with the airgun operations, an Atlas Hydrosweep DS-2 multibeam 15.5-kHz bathymetric sonar and a 3.5 kHz sub-bottom profiler were used by the geophysical science party to map the bathymetry to meet the project's scientific goals. While the *Ewing* was in the seismic study area, these two sources typically operated simultaneously with the seismic source. The two systems are mounted on the hull of the *Ewing* (Fig. C.3).

The ***Atlas Hydrosweep*** is specialized for mapping the bathymetry at deep (>500 m) water depths. However, it can operate in three modes, depending on the water depth. It has one shallow-water mode and two deep-water modes: an Omni mode and a Rotational Directional Transmission (RDT) mode. When water depth is <400 m, the shallow-water mode is used. The source output is 210 dB re 1 μPa · m rms and a single 1-millisecond pulse or "ping" per second is transmitted, with a beamwidth of 2.67º fore-aft and 90º athwartship. The beamwidth is measured to the –3 dB point, as is usually quoted for sonars. The Omni mode is identical to the shallow-water mode except that the source output is 220 dB re 1 μPa · m. The Omni mode is normally used only during start up. In the RDT mode, each "ping" consists of five successive transmissions, each ensonifying a beam that extends 2.67º fore-aft, and ~30º athwartships. The five successive transmissions (segments) sweep from port to starboard with minor overlap, spanning an overall cross-track angular extent of ~140º, with tiny (<<1 ms) gaps between the pulses for successive 30º segments. The total duration of the "ping", including all 5 successive segments, varies with water depth but is 1 ms in water depths <500 m and 10 ms in the deepest water. For each segment, ping duration is $1/5^{th}$ of these values or $2/5^{th}$ for a receiver in the overlap area ensonified by two beam segments. The "ping" interval during RDT operations depends on water depth and varies from once per second in <500 m water depth to once per 15 seconds in the deepest water.

The 3.5 kHz ***sub-bottom profiler*** is normally operated from aboard the *Ewing* to provide information about the sedimentary features and the bottom topography that is simultaneously being mapped by the Hydrosweep. The maximum source output (800 watts) of the sub-bottom profiler is 204 dB re 1 μPa, and the normal (500 watts) source output is 200 dB re 1 μPa. The energy from the sub-bottom profiler is directed downward by a 3.5 kHz transducer mounted in the hull of the *Ewing*. The output varies with water depth from 50 watts in shallow water to 800 watts in deep water. Pulse interval is 1 s but a common mode of operation is to broadcast five pulses at 1-s intervals followed by a 5-s pause.

The *Ewing*'s two standard vessel ***echosounders*** (i.e., fathometers) were the only other sonars operated during the cruise: a Furuno FGG80 echosounder and a Furuno FCU66 echosounder. These two systems were operated only to provide additional information on water depths for navigational safety purposes while traversing poorly-charted areas or while in and near ports. These general types of echosounders are standard equipment for large vessels.

APPENDIX D:
DETAILS OF MONITORING, MITIGATION, AND ANALYSIS METHODS

This appendix provides details on the standard visual and acoustic monitoring methods and data analysis techniques implemented for this project and previous L-DEO seismic studies from aboard the *Ewing*.

Résumés documenting the qualifications of the MMOs were provided to NMFS prior to commencement of the study. All MMOs participated in a review meeting before the start of the study, designed to familiarize them with the operational procedures and conditions for the cruise, reporting protocols, and IHA stipulations. In addition, implementation of the IHA requirements was explained to the Captain, Science Officer, Head Airgun Operator, and Science Party PIs aboard the vessel. MMO duties included

- watching for and identifying marine mammals and sea turtles, and recording their numbers, distances and behavior;
- noting possible reactions of marine mammals and sea turtles to the seismic operations;
- initiating mitigation measures when appropriate; and
- reporting the results.

Visual Monitoring Methods

Visual watches took place in the seismic survey area and during transits to and from the study area. In addition to conducting watches during seismic operations, MMOs also conducted daytime watches when the source vessel was underway but the airguns were not firing. This included ***(1)*** periods during transit to and from the seismic survey area, ***(2)*** a short "pre-seismic period" while equipment was being deployed, ***(3)*** periods when the seismic source stopped firing while equipment was being repaired, and ***(4)*** a short "post-seismic" period.

Visual observations were generally made from the *Ewing*'s flying bridge (Fig. C.1, C.5), the highest suitable vantage point on the *Ewing*. The observer's eye level was ~14.5 m (47 ft) above sea level. The flying bridge afforded a view of ~320º centered on the front of the *Ewing*, with partial obstructions to the stern (Fig. C.4). With two or more observers, one stationed on the port and one on the starboard side of the vessel, the partial obstruction was reduced to some extent. MMOs observed from the *Ewing*'s bridge during periods of poor weather. The observer's eye level on the bridge was ~11.7 m (38 ft) above sea level, with a field of view of ~135º.

A total of five observers trained in marine mammal identification and observation methods were present on the *Ewing* during the Chicxulub study. Visual watches aboard the *Ewing* were usually conducted in 1–2 h shifts (max. 4 h), alternating with PAM shifts and/or 1–4 h breaks, for a total of ~10 h per day per MMO during full-operation days. Daytime watches were conducted from dawn until dusk. MMO(s) scanned around the vessel, alternating between unaided eyes and 7×50 Fujinon binoculars. Occasionally scans were also made using the 25×150 Big-eye binoculars, to detect animals and to identify species or group size during sightings. Both the Fujinon and Big-eye binoculars were equipped with reticles on the ocular lens to measure depression angles relative to the horizon, an indicator of distance. During the day, at least one and (if possible) two MMOs were on duty, especially during the 30 min before and during ramp ups. For the Chicxulub study, no nighttime observations were conducted because seismic operations did not occur at night.

When MMO(s) were not on active duty at night, the *Ewing* bridge personnel were asked to watch for marine mammals and turtles during their regular watches. They were provided with a copy of the observer instruction manual and marine mammal identification guides that were kept on the bridge. If bridge crew sighted marine mammals or sea turtles at night, they were given instructions on how to fill out specific marine mammal and sea turtle sighting forms in order to collect pertinent information on sightings when MMOs were not on active duty. Bridge personnel would also look for marine mammals and turtles during the day, when MMO(s) were on duty.

While on watch, visual observers kept systematic written records of the vessel's position and activity, and environmental conditions. Codes that were used for this information are shown in Table D.1. Watch data were entered manually onto a datasheet every ~30 min, as activities allowed. Additional data were recorded when marine mammals or sea turtles were observed. For all records, the date and time (in GMT), vessel position (latitude, longitude), and environmental conditions were recorded. Environmental conditions also were recorded whenever they changed and with each sighting record. Standardized codes were used for the records, and written comments were usually added as well.

For each sighting, the following information was recorded: species, number of individuals seen, direction of movement relative to the vessel, vessel position and activity, sighting cue, behavior when first sighted, behavior after initial sighting, heading (relative to vessel), bearing (relative to vessel), distance, behavioral pace, species identification reliability, and environmental conditions. Codes that were used to record this information during the cruise are shown in Table D.1. Distances to groups were estimated from the MMO station on the flying bridge, rather than from the nominal center of the seismic source (the distance from the sighting to the airguns was calculated during analyses). However, for sightings near or within the safety radius in effect at the time, the distance from the sighting to the nearest airgun was estimated and recorded for the purposes of implementing power downs or shut downs. The bearing from the observation vessel to the nearest member of the group was estimated using positions on a clock face, with the bow of the vessel taken to be 12 o'clock and the stern at 6 o'clock.

Operational activities that were recorded by MMOs included the number of airguns in use, total volume of the airguns in use, and type of vessel/seismic activity. Vessel position and airgun activity (number and total volume of airguns) were available from a monitor on the *Ewing* flying bridge. That monitor was connected to the bridge navigational display monitor. The position of the vessel was automatically logged every minute by the *Ewing's* navigation system. Those data were used when detailed position information was required. In addition, the following information was recorded, if possible, for other vessels within 5 km (as specified in the IHA) at the time of a marine mammal sighting: vessel type, size, heading (relative to study vessel), bearing (relative to study vessel), distance, and activity. Inter-ship phone communication with the geophysicists and the MMO conducting PAM (in the ship's dry laboratory) was used to alert the visual MMOs to any changes in operations and any marine mammals detected acoustically.

All data were initially recorded on custom paper datasheets in the field and were entered into a Microsoft Excel® database at the end of the day. The database was constructed to prevent entry of out-of-range values and codes. Data entries were checked manually by comparing listings of the computerized data with the original handwritten datasheets, both in the field and upon later analyses. Data collected by the MMOs were also checked against the navigation and shot logs collected automatically by the vessel's computers, and manually against the geologists' project logs.

TABLE D.1. Summary of data codes used during the seismic survey.

WS	Watch Start
WE	Watch End
LINE	
Enter Line ID or leave blank	
SEISMIC ACTIVITY	
RU	Ramp-up
LS	Line Shooting
TR	Transiting @ < 2 kt
MI	Ship milling/stopped
DP	Deploying OBSs
RC	Recovering OBSs
SH	Shooting Between/Off.Lines
ST	Seismic Testing
SZ	Safety Zone Shut-Down
PD	Power-Down
SD	Shut-Down
OT	Other (comment and describe)
# GUNS	
Enter Number of Operating Airguns, or	
88	Varying (e.g., ramp-up)
99	Unknown
ARRAY VOLUME	
Enter operating volume, or	
99	Unknown
(BEAUFORT) SEA STATE	
See Beaufort Scale sheet.	
LIGHT OR DARK	
L	Light (day)
D	Darkness
GLARE AMOUNT	
NO	None
LI	Little
MO	Moderate
SE	Severe
POSITION	
Clock Position, or	
99	Variable (vessel turning)
WATER DEPTH	
In meters	
MARINE MAMMAL SPECIES	
Baleen Whales	
BLW	Blue Whale
BRW	Bryde's Whale
FW	Fin Whale
SW	Sei Whale
HW	Humpback Whale
MW	Minke Whale
UMW	Unidentified Mysticete Whale
UW	Unidentified Whale
Large Toothed Whales	
DSW	Dwarf Sperm Whale
FKW	False Killer Whale
KW	Killer Whale
MHW	Melon-headed Whale
PKW	Pygmy Killer Whale
PSW	Pygmy Sperm Whale
SPW	Sperm Whale
SFPW	Short-finned Pilot Whale
UTW	Unidentified Tooth Whale
Beaked Whales	
BBW	Blainville's Beaked Whale
CBW	Cuvier's Beaked Whale
GBW	Gervais' Beaked Whale
SBW	Sowerby's Beaked Whale
UBW	Unidentified Beaked Whale
Dolphins	
ASD	Atlantic Spotted Dolphin
BD	Bottlenose Dolphin
CD	Clymene Dolphin
FD	Fraser's Dolphin
LCD	Long-beaked Common Dolphin
PSP	Pantropical Spotted Dolphin
RD	Risso's Dolphin
RTD	Rough-toothed Dolphin
SCD	Short-beaked Common Dolphin
SPD	Spinner Dolphin
STD	Striped Dolphin
UD	Unidentified Dolphin
Pinnipeds	
HDS	Hooded Seal
TURTLE SPECIES	
GR	Green Turtle
HB	Hawksbill Turtle
KR	Kemp's Ridley Turtle
LH	Loggerhead Turtle
LB	Leatherback Turtle
UT	Unidentified Turtle
MOVEMENT	
PE	Perpendicular across bow
ST	Swim Toward
SA	Swim Away
FL	Flee
SP	Swim Parallel
MI	Mill
NO	No movement
UN	Unknown
INDIVIDUAL BEHAVIOR	
MA	Mating
SI	Sink
FD	Front Dive
TH	Thrash Dive
DI	Dive
LO	Look
LG	Logging
SW	Swim
BR	Breach
LT	Lobtail
SH	Spyhop
FS	Flipper Slap
FE	Feeding
FL	Fluking
BL	Blow
BO	Bow Riding
PO	Porpoising
RA	Rafting
WR	Wake Riding
AG	Approaching Guns
DE	Dead
OT	Other (describe)
NO	None (sign seen only)
UN	Unknown
GROUP BEHAVIOR (BEHAVIORAL STATES)	
TR	Travel
SA	Surface Active
ST	Surface Active-Travel
MI	Milling
FG	Feeding
RE	Resting
OT	Other (describe)
UN	Unknown
# RETICLES or ESTIMATE	
(of Initial Distance, etc.; Indicate Big eyes or Fujinons in comments)	
0 to 16	Number of reticles
E	Estimate, by eye
SIGHTING CUE	
BO	Body
HE	Head
SP	Splash
FL	Flukes
DO	Dorsal Fin
BL	Blow
BI	Birds
IDENTIFICATION RELIABILITY	
MA	Maybe
PR	Probably
PO	Positive
BEHAVIOR PACE	
SE	Sedate
MO	Moderate
VI	Vigorous
WITH ABOVE RECORD?	
Y	Yes
(blank)	not with above record

Passive Acoustic Monitoring Methods

Passive acoustic monitoring was conducted from aboard the *Ewing* to detect calling cetaceans and to alert visual MMOs to the presence of these animals. SEAMAP is the standard system typically used for PAM during L-DEO's seismic cruises. The SEAMAP system consists of hardware (i.e., the hydrophone) and a software program. The "wet end" of the SEAMAP system consists of a low-noise, towed hydrophone array that is connected to the vessel by a "hairy" faired cable. During this cruise, the array was deployed from a winch located on the back deck. A deck cable was connected from the winch to the main computer lab where the SEAMAP and signal conditioning and processing system were located.

The hydrophone array was 56 m in length and consisted of an active section of four hydrophones; only two hydrophones were monitored simultaneously with the SEAMAP system. The distance between the outer hydrophones was ~50 m. This separation distance is suitable for determining bearings, if possible, to most types of cetacean sounds (SEAMAP 2003). The length of the lead-in cable to the array was ~300 m and generally was fully deployed when the system was in use. The depth at which the hydrophone array was towed can be adjusted by adding or removing weights. During the Chicxulub survey, the hydrophone array was towed at variable depths due to shallow water in the study area.

Due to numerous problems with the SEAMAP software, a back-up software and recording system (SeaProUltra designed by CIBRA, University of Pavia, Italy) was usually used during the Chicxulub cruise. Details of the SEAMAP system and monitoring protocol are given below, followed by details about the CIBRA back-up system that was mainly used for recording of vocalizations during the cruise. The SEAMAP system (as well as the CIBRA system) was used to display the incoming signals on the monitor, but it could not be used to record or localize vocalizations. The CIBRA system was used to record vocalizations, but it was not capable of localizing vocalizations.

SEAMAP

SEAMAP software (version 1.525, Houston, TX) can be used for real-time processing of two channels of acoustic data from the array. GPS position is recorded automatically by SEAMAP software every minute. Integrated plotting software automatically displays the ship location, as well as a user-defined safety radius, graphically depicted as a colored ring centered on the airgun array. Waveform, spectral density, and a sound spectrogram are displayed using the SEAMAP software. Cross-correlation techniques are used to calculate the time delay between the signals arriving at two hydrophones in the SEAMAP array. A signal of interest (e.g., any signal believed to be a cetacean call) can be selected by the operator with a mouse using a "windowing" feature. The speed of sound, the time delay, and the distance between the two hydrophones are used to calculate the bearing to the selected signal. The bearing to the signal is graphically displayed on the plot display in SEAMAP.

For each bearing, there is also a "mirror-image" complementary bearing on the opposite side of the ship's trackline. When only one call is detected, it is not possible to distinguish reliably, from acoustic data alone, which of the two complementary bearings is the true bearing to the mammal.

With SEAMAP and similar systems, multiple bearings are necessary to obtain an animal location. This is accomplished by repeatedly obtaining bearings to an animal as the ship moves along a straight-line. The animal's location is determined by triangulating from two or more bearings; the point at which the bearing lines intersect is the estimated location of the animal. When only one call is detected, it is not possible to determine the animal's location. Also, if the animal is moving, there is some degree of error in the estimated location. When there are successive bearings to repeated calls by the same individual cetacean or group, SEAMAP can theoretically provide information on the distance of the vocalizing cetacean(s) from the hydrophone array. However, in practice, it is generally not possible to localize vocalizing cetaceans based on SEAMAP alone, for a number of reasons:

The SEAMAP software manual recommends that the monitoring vessel change its heading by ~10º between successive acoustic "fixes" in order to resolve the mirror-image ambiguity and to obtain distance information on vocalizing marine mammals. This is not possible during L-DEO cruises, as it is important for the primary purpose of the seismic survey, to maintain the planned straight-line transect. Also, the long streamer limits the *Ewing*'s turning ability.

When the calls are from a spread-out group of individuals, it is impossible to ascertain whether successive acoustic bearings are to the same animal or subgroup. With widespread groups, successive calls can originate from varying locations. The resultant sequence of bearings does not necessarily provide successive bearings to any one particular animal or subgroup.

The SEAMAP system is able to monitor broadband signals between ~8 Hz and 24 kHz. There are interference effects from ship noise and airgun sounds, although problems from ship noise appeared to be minimal. Hardware was used that filtered out sounds from airguns as they were fired (to make listening to the received signals more comfortable while using headphones). This filtering procedure filtered out all sounds for ~1–2 s so no other sounds could be heard during that interval. It is doubtful that any sequences of marine mammal vocalizations were missed as a result of the brief periods of "blanking" during the airgun shots. However, it appeared that the SEAMAP system has limited ability to detect low frequencies (<100 Hz) such as those that are typically produced by some baleen whales.

When cetacean calls are detected, and the signal-to-noise ratio of the vocalizing cetaceans is judged to be adequate, the acoustic data can (when the SEAMAP system is fully functional) be saved using a quick 2-min save function or a longer 10-min recording function.

Detailed instructions on the PAM protocol followed when using SEAMAP aboard the *Ewing* are described in a user manual written specifically for *Ewing* seismic cruises (Stoltz et al. 2004).

SeaProUltra and CIBRA Monitoring System as Used during the Cruise

The CIBRA software, SeaProUltra, was also used to monitor for vocalizing cetaceans detected via the SEAMAP hydrophones. SeaProUltra was initially used as a back-up system, but because of technical problems with the SEAMAP software, SeaProUltra was subsequently used as the main monitoring system. The CIBRA system functions included real-time spectrographic display, continuous and event audio recordings, navigation display, semi-automated data logging, and data logging display. These functions were similar to those of the SEAMAP system; however, the data logging capabilities are unique to the CIBRA system and are described briefly below. A document with detailed explanations of the CIBRA system is available from CIBRA (Pavan 2005).

When a vocalization was detected, information associated with that acoustic encounter was recorded. This included the acoustic encounter identification number, whether it was linked with a visual sighting, GMT date, GMT time when first and last heard and whenever any additional information was recorded, GPS position and water depth when first detected, species or species group (e.g., unidentified dolphins, sperm whales), types and nature of sounds heard (e.g., clicks, continuous, sporadic, whistles, creaks, burst pulses, strength of signal, etc.), and any other notable information. The data logger, developed by CIBRA, automatically read some of this information from the *Ewing*'s navigation data stream (GPS coordinates, time, and water depth) and fed it directly into a Microsoft Excel® data sheet, which could then be amended and edited with the additional information.

In addition to specific event logging, the acoustic MMO on duty noted the presence or absence of cetacean signals every 15 min. The acoustic MMO also noted the seismic state, vessel activity, and any changes in the numbers of airguns operating, based on information displayed on a monitor in the acoustic work area. The acoustic MMO notified the visual MMOs on the flying bridge of these changes via telephone or radio.

When the signal-to-noise ratio of vocalizing cetaceans was judged to be adequate (moderately strong and clear vocalizations), the acoustic data were recorded onto the computer hard-drive. The CIBRA system was capable of quick 2-min recordings, or continuous recordings of a user-defined time period.

Mitigation

Ramp-up, power-down, and shut-down procedures described briefly in Chapter 3 are described in detail below. These were the primary forms of mitigation implemented during seismic operations; in addition, seismic operations were not allowed during darkness. A ramp up consisted of a gradual increase in the number of operating airguns, not to exceed an increase of 6 dB in source level per 5 min-period, the maximum ramp-up rate authorized by NMFS in the IHA and during past L-DEO seismic cruises (Appendix A). A power down consisted of reducing the number of operating airguns to one operating airgun. A shut down occurred when all the airguns were turned off.

Ramp-up Procedures

A "ramp-up" procedure was followed at the commencement of seismic operations with the airgun array, and anytime after the array was powered down or shut down for a specified duration. Under normal operational conditions (vessel speed 4–5 kt), a ramp up to the full 20-airgun array was conducted after a shut down or power down lasting 8 min or longer.

The IHA required that, during the daytime, the entire safety radius be visible (i.e., not obscured by fog, etc.), and monitored for 30 min prior to and during ramp up, and that the ramp up could only commence if no marine mammals or sea turtles were detected within the safety radius during this period. Throughout the ramp ups, the safety zone was taken to be that appropriate for the entire airgun array and the water depth at the time, even though only a subset of the airguns were firing until the ramp up was completed. In addition, SEMARNAT and NMFS required that ramp-up and seismic operations could not occur during Beaufort Wind Force (Bf) >4 (i.e., wind speed >16 kt). (This requirement was amended during the cruise from the initial SEMARNAT requirement, which did not allow operations in Bf >2; this was deemed impractical.) Ramp up was to be suspended if marine mammals or turtles were detected within the safety radius or if Bf increased to >4. Ramp up of the airgun array was not permitted at night given the provisions of the IHA, i.e., no powering up unless entire safety zone is visible. Furthermore, SEMARNAT prohibited all airgun operations at night.

When no airguns were firing at the start of the ramp up, ramp up of the airgun array began with a single airgun. Airguns were added in a sequence such that the source level of the array would increase in steps not exceeding 6 dB per 5-min period (Appendix A).

Power-down and Shut-down Procedures

Airgun operations were immediately shut down or powered down to a single operational airgun when one or more marine mammals or sea turtles were detected within, or judged about to enter, the appropriate safety radius (see Table 3.1 in Chapter 3).

The power-down procedure was to be accomplished within several seconds (or a "one-shot" period) of the determination that a marine mammal or sea turtle was within or about to enter the safety radius. Airgun operations were not to resume until the animal was outside the safety radius, or had not been seen for a specified amount of time (15 min for dolphins, 25 min for turtles, and 30 min for whales). Once the safety radius was judged to be clear of marine mammals or sea turtles based on those criteria, the MMOs advised the airgun operators and geophysicists, who advised the bridge that seismic surveys could re-commence, and ramp up was initiated.

In contrast to a power down, a shut down refers to the complete cessation of firing by all airguns. If a marine mammal or turtle was seen within the designated safety radius around the one airgun in operation during a power down (Table 3.1), a complete shut down was necessary.

The MMOs were stationed on the flying bridge or bridge about 89 m ahead of the closest airgun in the array; the closest airgun was located ~34.5 m aft of the *Ewing*'s stern (Fig. 2.2). The decision to initiate a power down was based on the distance from the observers rather than from the array, unless the animals were sighted close to the array. This was another precautionary measure, given that most sightings were ahead of the vessel.

Analyses

This section describes the analyses of the marine mammal and sea turtle sightings and survey effort as documented during the cruise. It also describes the methods used to calculate densities and estimate the number of cetaceans potentially exposed to seismic sounds associated with the Chicxulub seismic survey. The analysis categories that were used were identified in Chapter 3. The primary analysis categories used to assess potential effects of seismic sounds on marine mammals were the "seismic" (airguns operating with shots at <1.5 min spacing) and "non-seismic" categories (periods before seismic started or >6 h after airguns were turned off). The analyses excluded the "post-seismic" period 1.5 min to 6 h after the airguns were turned off. The justification for the selection of these criteria is based on the size of the array in use and is provided below. These criteria were discussed in earlier L-DEO cruise reports to NMFS (see Haley and Koski 2004; Smultea et al. 2004, 2005; MacLean and Koski 2005; Holst et al. 2005):

- The period up to 1.5 min after the last seismic shot is ~10× the normal shot interval. Mammal distribution and behavior during that short period are assumed to be similar to those while seismic surveying is ongoing.
- It is likely that any marine mammals near the *Ewing* between 1.5 min and 2 h after the cessation of seismic activities would have been "recently exposed" (i.e., within the past 2 h) to sounds from the seismic survey. During at least a part of that period, the distribution and perhaps behavior of the marine mammals probably would still be influenced by the (previous) sounds.
- For some unknown part of the period from 2 to 6 h post-seismic, it is possible that the distribution of the animals near the ship, and perhaps the behavior of some of those animals, would still be at least slightly affected by the (previous) seismic sounds.

- By 6 h after the cessation of seismic operations, the distribution and behavior of marine mammals would be expected to be indistinguishable from "normal" because of (a) waning of responses to past seismic activity, (b) re-distribution of mobile animals, and (c) movement of the ship and MMOs. Given those considerations, plus the limited observed responses of marine mammals to seismic surveys (e.g., Stone 2003; Gordon et al. 2004; and previous L-DEO projects), it is unlikely that the distribution or behavior of marine mammals near the *Ewing* >6 h post-seismic would be appreciably different from "normal" even if they had been exposed to seismic sounds earlier. Therefore, we consider animals seen >6 h after cessation of operations by the 20-airgun array to be unaffected by the seismic operations.

As summarized in Chapter 3, cetacean density was one of the parameters examined to assess differences in the distribution of cetaceans relative to the seismic vessel between seismic and non-seismic periods. Line transect procedure for vessel-based visual surveys were followed. To allow for animals missed during daylight, we corrected our visual observations for missed cetaceans by using approximate correction factors derived from previous studies. (It was not practical to derive study-specific correction factors during a survey of this type and duration.) It is recognized that the most appropriate correction factors will depend on specific observation procedures during different studies, ship speed, and other variables. Thus, use of correction factors derived from other studies is not ideal, but it provides more realistic estimates of numbers present than could be obtained without using data from other studies.

The formulas for calculating densities using this procedure were briefly described in Chapter 3 and are described in more detail below. As standard for line-transect estimation procedures, densities were corrected for the following two parameters before they were further analyzed:

- $g(0)$, a measure of detection bias. This factor allows for the fact that less than 100% of the animals present along the trackline are detected.
- $f(0)$, the reduced probability of detecting an animal with increasing distance from the track-line.

The $g(0)$ and $f(0)$ factors used in this study were taken from results of previous work, not from observations made during this study. Sighting rates during the present study were either too small or, at most, marginal to provide meaningful data on $f(0)$ based on group size. Further, this type of project cannot provide data on $g(0)$. Estimates of these correction factors were derived from Koski et al. (1998), Mullin and Hoggard (2000), and Ortega-Ortiz (2002), for corresponding species and Beaufort Wind Forces. Marine mammal sightings were subjected to species-specific truncation criteria obtained from the above studies. It should be recognized that the use of $f(0)$ and $g(0)$ factors from other studies conducted in other locations is a first approximation, with no allowance for differences in observation procedures, ship speeds, etc. However, the use of these "best available" correction factors is preferable to the alternative of ignoring the need for such factors.

Number of Exposures.—Estimates of the numbers of potential *exposures* of marine mammals to sound levels ≥160 dB re 1 µPa (rms) were calculated by multiplying the following three values. These calculations were done separately for times when different numbers of airguns were in use, and the results were summed:

- number of kilometers of seismic survey,
- width of the area assumed to be ensonified to ≥160 dB (2 × 160 dB radius, depending on the airgun(s) in use at the time; Table 3.1), and
- "corrected" densities of marine mammals estimated by line transect methods as summarized above.

Number of Individuals Exposed.—The estimated number of individual exposures to levels ≥160 dB obtained by the method described above likely overestimates the number of different *individual* mammals exposed to the airgun sounds at received levels ≥160 dB. This occurs because some exposure incidents may have involved the same individuals previously exposed, given that some seismic lines crossed other lines and were closely spaced (see Fig. 1.1).

A minimum estimate of the number of different individual marine mammals potentially exposed (one or more times) to ≥160 dB re 1 µPa (rms) was calculated. That involved multiplying the corrected density of marine mammals by the area exposed to ≥160 dB one or more times during the course of the study. The area was calculated using MapInfo Geographic Information System (GIS) software by creating a "buffer" that extended on both sides of the vessel's trackline to the predicted 160-dB radius. Because the 160-dB radius varied with the number of airguns in use (Table 3.1), the width of the buffer also varied with the number of airguns in use. The buffer includes areas that were exposed to airgun sounds ≥160 dB multiple times (as a result of crossing tracklines or tracklines that were close enough for their 160 dB zones to overlap). The buffer area only counts the repeated-coverage areas once, as opposed to the "exposures" method outlined above (Table D.2). The calculated number of different individual marine mammals exposed to ≥160 dB re 1 µPa (rms) is considered a minimum estimate because it does not account for the movement of marine mammals during the course of the study.

The buffer process outlined above was repeated for delphinids, assuming that for those animals, the estimated 170 dB radius (see Table 3.1) was a more realistic estimate of the maximum distance at which significant disturbance would occur. That radius was used to estimate both the number of exposures and the number of individuals exposed to seismic sounds with received levels ≥170 dB re 1 µPa (rms). The process was also repeated for all cetacean species based on the estimated 180-db radius. That was done to estimate the numbers of animals that would have been subjected to sounds with received levels ≥180 dB re 1 µPa (rms) if they had not altered their course to avoid those sound levels (or the ship).

TABLE D.2. The areas (km^2) potentially ensonified to various levels (in dB re 1 µPa, rms) by airguns operating in the shallow (<100 m) water depths of the study area during the Chicxulub seismic cruise, 7 Jan. - 20 Feb. 2005. ***(A)*** Maximum area ensonified, with overlapping areas counted multiple times. ***(B)*** Total area ensonified at least once, with overlapping areas counted only once.

	Sound Criterion for Water Depth <100 m				
Area (km^2)	160 dB	170 dB	180 dB	190 dB	Total
A. Including Overlap Area	8052	14,663	32,739	67,496	122,950
B. Excluding Overlap Area	5556	8141	13,672	22,700	50,068

APPENDIX E:
BACKGROUND ON MARINE MAMMALS IN THE CHICXULUB PROJECT REGION

TABLE E.1. The habitat, abundance, and conservation status of marine mammals that are known to occur in the Gulf of Mexico. For species that occur commonly in the Gulf at water depths <200 m, the "Species", "Habitat" and "Occurrence in the Gulf of Mexico" entries are in boldface.

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and in North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
Odontocetes						
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Common	530 (0.31)[a] *13,190* [b]	Endangered*	VU	I
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off the shelf	Common	733[c,d] *536 (0.45)* [e,d]	Not listed	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deeper waters off the shelf	Common	N.A.	Not listed	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Rare	159[c] *3196 (0.34)* [e,f]	Not listed	DD	II
Sowerby's beaked whale (*Mesoplodon bidens*)	Pelagic	Extralimital; not seen in southern Gulf	117 (0.38)[a,g]	Not listed	DD	II
Gervais' beaked whale (*Mesoplodon europaeus*)	Pelagic	Uncommon	N.A.	Not listed	DD	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	Rare	N.A.	Not listed	DD	II
Rough-toothed dolphin (*Steno bredanensis*)	Mostly pelagic	Common	852 (0.31)[a]	Not listed	DD	II
Bottlenose dolphin (*Tursiops truncatus*)	**Continental Shelf, coastal** and offshore	**Common**	5618 (0.26)[h] 50,247 (0.18)[I] 3499 (0.21)[j] 4191 (0.21)[k] 9912 (0.12)[m] 5141[n] *50,092* [e,o]	Not listed[§]	DD	II
Pantropical spotted dolphin (*Stenella attenuata*)	Mainly pelagic	Common	46,625[c] *13,117 (0.56)*[e]	Not listed	LR-cd	II
Atlantic spotted dolphin (*Stenella frontalis*)	**Mainly coastal waters**	**Common**	3213[a] *52,279* [p]	Not listed	DD	II
Spinner dolphin (*Stenella longirostris*)	Pelagic in Gulf of Mexico	Common	11,251[c]	Not listed	LR-cd	II

Species	**Habitat**	**Occurrence in Gulf of Mexico**[1]	**Abundance in Gulf and in North Atlantic**[2]	**ESA**[3]	**IUCN**[4]	**CITES**[5]
Clymene dolphin (*Stenella clymene*)	Pelagic	Common	10,093[c]	Not Listed	DD	II
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	Common	4858 (0.44)[a] *61,546 (0.40)*[e]	Not listed	LR-cd	II
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic waters	Possible	N.A.	Not listed*	N.A.	II[+]
Long-beaked common dolphin (*Delphinus capensis*)	Coastal	Possible	N.A.	Not Listed	N.A.	II[+]
Fraser's dolphin (*Lagenodelphis hosei*)	Water >1000 m	Common; has not been seen in study area	127 (0.90)[a]	Not listed	DD	II
Risso's dolphin (*Grampus griseus*)	Waters 400-1000 m	Common	3040[c] *29,110 (0.29)*[e]	Not listed	DD	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	Common	3965 (0.39)[a]	Not listed	N.A.	II
Pygmy killer whale (*Feresa attenuata*)	Oceanic	Uncommon	518 (0.81)[a]	Not listed	DD	II
False killer whale (*Pseudorca crassidens*)	Pelagic	Uncommon	817[c]	Not listed	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	Uncommon	277 (0.42)[a] *6600* [q]	Not listed	LR-cd	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	Common	1471[c] *792,524* [r]	Not listed*	LR-cd	II
Long-finned pilot whale (*Globicephala melas*)	Mostly pelagic	Possible	N.A.	Not listed*	N.A.	II
Mysticetes North Atlantic right whale (*Eubalaena glacialis*)	Coastal and shelf waters	Extralimital; not seen in southern Gulf	291[e]	Endangered*	EN	I
Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters and banks	Rare	*11,570* [s] *10,600* [t] *10,000* [u]	Endangered*	VU	I
Minke whale (*Balaenoptera acutorostrata*)	Coastal waters	Rare	*149,000* [v]	Not listed	LR-nt	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	Uncommon; not seen in southern Gulf	35 (1.10)[a]	Not listed	DD	I

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and in North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Rare	*12-13,000* [w]	Endangered*	EN	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Rare	2814[e] *47,300* [v]	Endangered*	EN	I
Blue whale (*Balaenoptera musculus*)	Coastal, shelf, and oceanic waters	Extralimital	*308*[e,x]	Endangered*	EN	I
Sirenian West Indian manatee (*Trichechus manatus*)	Freshwater and coastal waters	Common along the coast of Florida; Rare in other parts of the Gulf	86[y] 340[z]	Endangered*	VU	I
Pinnipeds Hooded seal (*Cystophora cristata*)	Coastal	Vagrant	*300,000*^	Not listed	N.A.	N.A.

N.A. - Data not available or species status was not assessed.
[1] Occurrence from Würsig et al. (2000).
[2] Estimate for North Atlantic population shown in italics. The Coefficient of Variation (CV) is a measure of a number's uncertainty or variability on a proportional basis and is shown in brackets.
[3] Endangered Species Act (Waring et al. 2001, 2002).
[4] Codes for IUCN classifications: EN = Endangered; VU = Vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened); DD = Data Deficient. Classifications are from the 2003 IUCN *Red List of Threatened Species,* although the status of marine mammals has not been reassessed since 1996.
[5] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2002).
* Listed as a strategic stock under the U.S. Marine Mammal Protection Act.
§ Only the Gulf of Mexico bay, sound, and estuarine stocks are strategic.
[a] Abundance estimate for the northern Gulf of Mexico stock from Waring et al. (2001, 2002).
[b] *g*(o) corrected total estimate for the Northeast Atlantic, Faroes-Iceland, and the U.S. east coast (Whitehead 2002).
[c] Abundance estimate for the northern Gulf of Mexico stock from Davis et al. (2000).
[d] Estimate for *Kogia* sp.
[e] Abundance estimate for U.S. Western North Atlantic stocks (Waring et al. 2002).
[f] This estimate is for *Mesoplodon* and *Ziphius* spp.
[g] Estimate for all *Mesoplodon* spp. and perhaps including some *Ziphius* spp.
[h] Gulf of Mexico continental shelf edge and continental slope stock.
[i] Gulf of Mexico outer continental stock (Waring et al. 2002).
[j] Western Gulf of Mexico coastal stock (Waring et al. 2002).
[k] Northern Gulf of Mexico coastal stock (Waring et al. 2002).
[m] Eastern Gulf of Mexico coastal stock (Waring et al. 2002).
[n] Gulf of Mexico bay, sound, and estuarine stocks (Waring et al. 2002).
[o] Abundance estimate is a total for the Western North Atlantic offshore and coastal stock.
[p] Abundance estimate for the Western North Atlantic offshore and coastal stocks combined.
[q] Estimate for Icelandic and Faroese waters (Reyes 1991).
[r] This is a combined estimate for *Globicephala sp.* for the Northeast Atlantic (Buckland et al. 1993) and for the Western North

Atlantic stock (Waring et al. 2002).
[s] This estimate is for the Atlantic Basin (Stevick et al. 2001, 2003).
[t] Estimate for the entire North Atlantic (Smith et al. 1999).
[u] Estimate for the Southern Hemisphere (IWC 2003).
[v] Estimate is for the North Atlantic (IWC 2003).
[w] Abundance estimate for the North Atlantic (Cattanach et al. 1993).
[x] Minimum abundance estimate.
[y] Antillean Stock in Puerto Rico only.
[z] Antillean Stock in Belize (Reeves et al. 2002).
[^] Estimate for the northwest Atlantic (Seal Conservation Society 2001).
[+] No distinction is made between *D. delphis* and *D. capensis*.

APPENDIX F:
VISUAL AND ACOUSTIC EFFORT AND DETECTIONS

TABLE F.1. All and useable[a] visual observation effort from the *Ewing* within the Chicxulub study area, 7 Jan.–20 Feb. 2005, in ***(A)*** hours, and ***(B)*** kilometers, subdivided by water depth and airgun status. Ramp-up effort is included in the "Airguns On" category.

	Water Depth (m)						
	All Effort			Useable Effort			
Airgun Status **Water Depth**	**<100 m**	**100-1000 m**	**>1000 m**	**<100 m**	**100-1000 m**	**>1000 m**	**Total**
(A) Effort in h							
Total Airguns On (Seismic)	***205***	***0***	***0***	***201***	***0***	***0***	***205***
Seismic Testing	1	0	0	1	0	0	1
Total Airguns Off	***729***	***10***	***48***	***127***	***6***	***14***	***787***
Post-seismic testing	6	0	0	0	0	0	6
Pre-seismic	148	0	0	57	0	0	148
>90 s - 6 h Post-seismic	67	0	0	12	0	0	67
Non-seismic (>6 h since seismic)	427	0	0	50	0	0	427
Non-seismic transit from Colon, Panama[b]	80	10	48	7	6	14	138
Non-seismic transit to Progreso, Mexico	1	0	0	0	0	0	1
Total Airguns On + Off	**933**	**10**	**48**	**327**	**6**	**14**	**991**
(B) Effort in km							
Total Airguns On (Seismic)	***1892***	***0***	***0***	***1855***	***0***	***0***	***1892***
Seismic Testing	8	0	0	8	0	0	8
Total Airguns Off	***6377***	***225***	***982***	***1405***	***134***	***284***	***7584***
Post-seismic testing	34	0	0	0	0	0	34
Pre-seismic	1330	0	0	599	0	0	1330
>90 s - 6 h Post-seismic	495	0	0	144	0	0	495
Non-seismic (>6 h since seismic)	3987	0	0	542	0	0	3987
Non-seismic transit from Colon, Panama[b]	515	225	982	120	134	284	1722
Non-seismic transit to Progreso, Mexico	16	0	0	0	0	0	16
Total Airguns On + Off	**8269**	**225**	**982**	**3252**	**134**	**284**	**9476**

[a] See *Acronyms and Abbreviations* for the definition of "useable".

[b] Effort within this table is limited to the visual effort conducted within the Chicxulub study area. As described in Chapter 3, the study area was defined as shiptracks located within the Caribbean Ecological Province of the Atlantic Trade Wind Biome as identified in Longhurst (1998). Thus, a total of 422 km of visual effort was excluded from data analyses because it was located outside the study area within the Guianas Coastal Province of the Atlantic Coastal Biome during the early portion part of the initial transit to Panama (Longhurst 1998).

TABLE F.2. All (and useable[a]) visual observation effort from the *Ewing* within the Chicxulub study area, 7 Jan. - 20 Feb. 2005, in ***(A)*** hours, and ***(B)*** kilometers, subdivided by Beaufort Wind Force (Bf) and airgun status. Ramp-up effort is included in the "Airguns On" category.

	Beaufort Wind Force							
Airgun Status	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
(A) Effort in h								
Total Airguns On (Seismic)	***0***	***3***	***15***	***71(70)***	***115(112)***	***0***	***0***	***205(201)***
1–90 s after shutdown	0	0	0	0	1(1)	0	0	2
Ramp-up[b]	0	1	3	5	14	0	0	23(22)
1 airgun on	0	0	0	2	1	0	0	3
2-6 airguns on	0	0	0	0	0	0	0	0
7-10 airguns on	0	0	0	0	0	0	0	0
11-15 airguns on	0	0	0	0	0	0	0	0
16-19 airguns on	0	0	0	8	9(8)	0	0	16
20 airguns on	0	2	13	28	93(90)	0	0	166(163)
Total Airguns Off	***0***	***0***	***9(6)***	***40(26)***	***54(37)***	***108(70)***	***18(0)***	***230(139)***
Pre-seismic	0	0	0	12(11)	17(16)	33(28)	10(0)	72(56)
>90 s - 6 h Post-seismic	0	0	0	6(3)	15(7)	2(1)	0	23(11)
Non-seismic (>6 h since seismic on)	0	0	9(6)	16(6)	19(11)	56(26)	5	106(49)
Non-seismic transit from Colon, Panama	0	0	0	5(5)	4(3)	16	3(0)	29(23)
Non-seismic transit to Progreso, Mexico	0	0	0	0	0	0	0	0
Total Airguns On + Off	**0**	**3**	**24(22)**	**110(96)**	**170(149)**	**108(70)**	**18(0)**	**434(340)**
(B) Effort in km								
Total Airguns On (Seismic)	***0***	***25***	***180***	***637(633)***	***1046(1013)***	***4(4)***	***0***	***1892(1855)***
1–90 s after shutdown	0	0	4(4)	4(4)	7(7)	4(4)	0	19(18)
Ramp-up[b]	0	5(5)	30(30)	41(41)	127(121)	0	0	203(197)
1 airgun on	0	0	4	22	5	0	0	31
2-6 airguns on	0	0	0	0	0	0	0	0
7-10 airguns on	0	0	0	0	0	0	0	0
11-15 airguns on	0	0	0	0	0	0	0	0
16-19 airguns on	0	0	0	64	79(78)	0	0	143(141)
20 airguns on	0	20	142	506(502)	828(803)	0	0	1497(1467)
Total Airguns Off	***0***	***3(0)***	***110(97)***	***383(296)***	***510(407)***	***1176(908)***	***206(0)***	***2389(1707)***
Pre-seismic	0	0	0	103(102)	172(171)	322(309)	97(0)	694(583)
>90 s - 6 h Post-seismic	0	0	0	40(34)	114(91)	15(3)	0	169(127)
Non-seismic (>6 h since seismic on)	0	3(0)	110(97)	150(69)	169(93)	509(268)	46(0)	988(528)
Non-seismic transit from Colon, Panama	0	0	0	90	55(51)	330(328)	63(0)	538(470)
Non-seismic transit to Progreso, Mexico	0	0	0	0	0	0	0	0
Total Airguns On + Off	**0**	**28(25)**	**290(277)**	**1021(929)**	**1556(1420)**	**1180(912)**	**206(0)**	**4281(3562)**

[a] See *Acronyms and Abbreviations* for the definition of "useable".

[b] Ramp up involved gradually increasing the number of operating airguns from 0 or 1 airgun at a rate of no greater than ~6 dB per 5-min period, typically until all airguns were operating.

TABLE F.3. Visual sightings and acoustic detections of cetaceans made from the R/V *Maurice Ewing* in the Chicxulub study area off the northern Yucatán Peninsula in the southern Gulf of Mexico, 7 Jan.–20 Feb. 2005. Only delphinids were seen or heard during the survey.

Species	Vis. (V) or Acoust. (A) Detection	Useable (Y) or Non-Useable (N)[a]	Grp Size	Day in 2005	Time (GMT)	Lat. (°N)	Long. (°N)	Initial Sighting Distance (m) from Airgun Array	CPA[b] (m) (Distance from Cetacean Group to Airgun Array)	Initial Move-ment[c]	Initial Behav.[d]	Bf[e]	Water Depth (m)[f]	Vessel Activ.[g]	# Guns On	Array Vol. (in^3)	Light (L) or Dark (D)	Mitig. (SZ, PD, None)[h]
Pantropical spotted dolphin	V	N	10	8-Jan	18:52:11	13.1823	-80.4209	229	95	ST	PO	6	2364	OT	0	0	L	None
Atlantic spotted dolphin	V	Y	10	9-Jan	13:53:48	16.5141	-80.9702	117	87	ST	SW	5	517	OT	0	0	L	None
Unidentified dolphin	V	Y	2	9-Jan	14:14:05	16.5758	-81.0079	136	92	ST	PO	5	512	OT	0	0	L	None
Bottlenose dolphin	V	Y	2	11-Jan	14:42:32	21.8664	-88.2485	123	104	SP	SW	3	19	OT	0	0	L	None
Bottlenose dolphin	V	Y	6	11-Jan	16:01:24	21.8879	-88.4609	104	104	SA	SW	3	22	OT	0	0	L	None
Bottlenose dolphin	V	Y	12	11-Jan	18:06:41	22.2503	-88.4069	730	109	ST	PO	3	40	OT	0	0	L	None
Bottlenose dolphin	V	Y	6	14-Jan	19:13:23	21.8811	-89.4853	701	229	ST	SW	5	36	TR	0	0	L	None
Atlantic spotted dolphin	V	Y	4	17-Jan	18:52:13	21.6571	-90.1650	162	162	UN	PO	4	32	TR	0	0	L	None
Unidentified dolphin	V	Y	2	18-Jan	19:56:44	21.6839	-89.7437	400	175	PE	SW	5	28	TR	0	0	L	None
Atlantic spotted dolphin	V	Y	4	18-Jan	20:19:16	21.6904	-89.7134	587	147	ST	SW	5	27	TR	0	0	L	None
Atlantic spotted dolphin	V	Y	12	20-Jan	15:02:53	21.6245	-90.0213	400	92	SP	SW	3	24	TR	0	0	L	None
Unidentified dolphin	V	N	1	22-Jan	23:50:00	21.6863	-89.2770	686	686	UN	SW	5	22	TR	0	0	L	None
Unidentified dolphin	V	N	1	23-Jan	17:00:00	21.5467	-89.7322	3783	3783	UN	UN	1	20	RU	16	99	L	None
Atlantic spotted dolphin	V	Y	2	24-Jan	14:41:38	21.4400	-90.0063	303	207	SP	SW	4	18	PD	1	80	L	PD
Unidentified dolphin	A	Y		28-Jan	13:48:18	21.3640	-90.7490					5	25	TR	0	0	L	None
Unidentified dolphin	A	Y		28-Jan	21:07:36	21.3159	-90.4239					5	19	TR	0	0	L	None
Bottlenose dolphin	V	N	5	28-Jan	21:07:49	21.3160	-90.4236	427	109	ST	SW	5	19	TR	0	0	L	None
Unidentified dolphin	A	Y		29-Jan	11:57:26	21.4845	-90.3566						25	TR	0	0	D	None
Unidentified dolphin	A	Y		29-Jan	13:40:46	21.6113	-90.2991					4	32	LS	20	6947	L	None
Unidentified dolphin	V	Y	1	1-Feb	15:21:32	21.5194	-89.4262	1039	996	SP	SW	4	15	PD	1	80	L	PD
Bottlenose dolphin	V	N	10	2-Feb	19:15:34	21.3475	-90.0238	151	151	MI	PO	4	27	TR	0	0	L	None
Unidentified dolphin	V	Y	8	3-Feb	19:19:48	21.6029	-89.8687	458	353	MI	SW	3	24	TR	0	0	L	None
Atlantic spotted dolphin	V	Y	2	5-Feb	12:27:59	21.6933	-89.7912	92	87	MI	SW	4	27	TR	0	0	L	None
Unidentified dolphin	A	Y		5-Feb	13:12:46	21.6961	-89.8536					4	31	TR	0	0	L	None
Atlantic spotted dolphin	V	Y	2	9-Feb	16:28:00	21.5477	-89.4007	676	278	SP	SW	3	16	PD	1	80	L	PD
Unidentified dolphin	A	Y		10-Feb	12:35:58	21.5174	-90.2088					4	24	TR	0	0	L	None
Unidentified dolphin	A	Y		11-Feb	12:34:52	21.7611	-89.8107					5	33	TR	0	0	L	None
Unidentified dolphin	V	Y	10	11-Feb	13:46:00	21.6805	-89.7700	576	576	UN	UN	5	26	TR	0	0	L	None
Unidentified dolphin	A	Y		12-Feb	11:54:02	21.8129	-89.2447						30	TR	0	0	D	None
Unidentified dolphin	A	Y		14-Feb	16:15:42	21.5598	-89.5660					2	20	LS	20	6947	L	None
Unidentified dolphin	A	Y		17-Feb	11:38:38	21.7763	-89.1978						23	TR	0	0	D	None
Bottlenose dolphin	V	Y	1	17-Feb	16:12:00	21.6918	-89.6000	107	107	PE	SW	2	28	SZ	0	0	L	SZ
Unidentified dolphin	A	Y		17-Feb	17:34:26	21.6666	-89.7205					2	27	LS	20	6947	L	None
Unidentified dolphin	V	Y	1	17-Feb	17:40:27	21.6647	-89.7294	2033	916	SA	SW	2	25	PD	1	80	L	PD
Bottlenose dolphin	V	Y	5	17-Feb	17:53:57	21.6605	-89.7492	941	328	SP	SW	2	26	SH	1	80	L	None
Bottlenose dolphin	A	Y		17-Feb	17:58:52	21.6590	-89.7564					2	27	SH	1	80	L	None
Unidentified dolphin	A	Y		17-Feb	18:49:52	21.6433	-89.8308					3	25	SH	1	80	L	None

[a] Useable or Non-useable sightings. Y=Visual sightings made during daylight periods within the study area, N=periods 90 s to 6 h after airguns were turned off (post-seismic), nighttime observations, poor visibility conditions (visibility <3.5 km), and periods with Beaufort Wind Force >5 (>2 for cryptic species). Also excluded were periods when the *Ewing*'s speed was <3.7 km/h (2 kt) or with >60º of severe glare between 90º left and 90º right of the bow.

[b] CPA is the distance at the closest observed point of approach to the nearest airgun. This is not necessarily the distance at which the individual or group was initially seen nor the closest it was observed to the vessel.

[c] The initial movement of the individual or group relative to the vessel. MI=milling, PE=swimming perpendicular to ship or across bow, SA=swimming away, SP=swimming parallel, ST=swimming toward, UN=unknown.

[d] The initial behavior observed. PO=porpoising, SW=swimming, UN=unknown.

[e] Beaufort Wind Force scale (which is not the same as the "Sea State" scale).

[f] Water depth was recorded for the vessel's location when a sighting was made. Depths shown as a<100 are between 0 and 100m; b100-1000 are between 100 and 1000m; c>1000 are between 1000 and 6000m.

[g] Activity of the vessel at the time of the sighting. LS=operating airguns on a seismic survey line and collecting geophysical data, OT=other (a period of no seismic activity either during transit or a period after an SZ), PD=power down of airguns, RU=ramp up, SH=operating airguns offline usually during turns between seismic lines, SZ=sound radius shut down, TR=transiting at speeds of ≥2 kt

[h] Mitigating measures. SZ= safety zone shut down, PD=power down, None.

TABLE F.4. Total number of groups (individuals in parentheses) of cetaceans observed from the *Ewing* by species, seismic activity, and transit periods during the Chicxulub seismic cruise, 7 Jan. - 20 Feb. 2005. See Table 4.1 for the total number of useable[a] sightings (a subtotal of the numbers shown here). Delphinids were the only marine mammals seen during the cruise.

	Within and Between Seismic Grids[b]				Transit (Non-seismic)			
Species	**Pre-seismic**	**Seismic**	**90 s - 6 h Post-Seismic**	**Non-seismic (>6 h after airguns stopped)**	**Transit from Panama**	**Return Transit to Progreso, Mexico[c]**	**Total Group Sightings**	**Total Indiv.**
Bottlenose dolphin	1(6)	2(6)	2(15)	0	3(20)	0	8	47
Atlantic spotted dolphin	3(20)	2(4)	0	1(2)	1(10)	0	7	36
Pantropical spotted	0	0	0	0	1(10)	0	1	10
Unidentified dolphin	1(2)	3(3)	1(1)	2(18)	1(2)	0	8	26
Total Cetaceans	**5(28)**	**7(13)**	**3(16)**	**3(20)**	**6(42)**	**0**	**24**	**119**

[a] See *Acronyms and Abbreviations* for the definition of “useable”.

[b] See Figure 2.1 for locations of grid where seismic survey lines were located.

[c] "Transit" excludes the first portion of the initial transit from Panama to Mexico, which was located outside the Caribbean Ecological Province (Longhurst 1998) and thus outside the Chicxulub study area (see Chapter 3 *Analyses*). These data were excluded from data analyses. "Transit" excludes the seismic-survey area identified in footnote b above.

TABLE F.5. All (and useable[a]) passive acoustic monitoring (PAM) effort conducted from the *Ewing* within the Chicxulub study area[b], 7 Jan. - 20 Feb. 2005, in ***(A)*** hours, and ***(B)*** kilometers, subdivided by airgun status. Ramp-up effort is included in the "Airguns On" category[c].

		Night		Day		Total	
Airgun Status	**Water Depth**	**All**	**Useable**	**All**	**Useable**	**All**	**Useable**
(A) Effort in h							
Total Airguns On (Seismic)		***0***	***0***	***205***	***201***	***205***	***201***
	1–90 s after shutdown	0	0	2	2	2	2
	Ramp-up	0	0	23	22	23	22
	1 airgun on	0	0	3	3	3	3
	2-6 airguns on	0	0	0	0	0	0
	7-10 airguns on	0	0	0	0	0	0
	11-15 airguns on	0	0	0	0	0	0
	16-19 airguns on	0	0	16	16	16	16
	20 airguns on	0	0	161	158	161	158
Total Airguns Off		***18***	***0***	***100***	***51***	***118***	***51***
	Pre-seismic	2	0	19	19	21	19
	>90 s - 6 h Post-seismic	4	0	48	0	52	0
	Non-seismic (>6 h since seismic on)	12	0	33	32	45	32
	Non-seismic transit from Colon, Panama	0	0	0	0	0	0
	Non-seismic transit to Progreso, Mexico	0	0	0	0	0	0
Total Airguns On + Off		**19**	**0**	**303**	**251**	**322**	**251**
(B) Effort in km							
Total Airguns On (Seismic)		***0***	***0***	***1885***	***1846***	***1885***	***1846***
	1–90 s after shutdown	0	0	19	18	19	18
	Ramp-up	0	0	203	197	203	197
	1 airgun on	0	0	23	23	23	23
	2-6 airguns on	0	0	0	0	0	0
	7-10 airguns on	0	0	0	0	0	0
	11-15 airguns on	0	0	0	0	0	0
	16-19 airguns on	0	0	143	141	143	141
	20 airguns on	0	0	1497	1467	1497	1467
Total Airguns Off		***168***	***0***	***853***	***434***	***1051***	***434***
	Pre-seismic	18	0	159	159	178	159
	>90 s - 6 h Post-seismic	42	0	411	0	482	0
	Non-seismic (>6 h since seismic on)	108	0	283	275	391	275
	Non-seismic transit from Colon, Panama	0	0	0	0	0	0
	Non-seismic transit to Progreso, Mexico	0	0	0	0	0	0
Total Airguns On + Off		**168**	**0**	**2767**	**2282**	**2935**	**2282**

[a] "Useable" PAM effort was PAM effort that overlapped useable visual effort. See *Acronyms and Abbreviations* for the definition of "useable".

[b] See Table F.1 or Chapter 3 *Analyses* for the definition of the Chicxulub study area used in analyses.

[c] Ramp up involved gradually increasing the number of operating airguns from 0 or more ariguns at a rate of no greater than ~6 dB per 5-min period, typically until all airguns were operating.

APPENDIX G:
SIGHTINGS WITH POWER DOWNS AND SHUT DOWNS DURING THE CHICXULUB CRUISE

There were four power downs and one shut down of the airgun array due to dolphin sightings within the nominal 180 dB safety radius during the Chicxulub cruise. All five sightings occurred in shallow water (less than ~30 m deep), where the defined safety radius was 3500 m (Table 3.1). Four dolphin groups were likely exposed to levels ≥180 dB, and the remaining one group was definitely exposed to levels ≥180 dB, as follows:

- Two Atlantic spotted dolphins were seen on 24 Jan. at 14:26 GMT during ramp up of the airgun array in water ~18 m deep. The dolphin group consisted of an adult and one juvenile. The dolphins were initially seen swimming in the same direction and parallel to the *Ewing* ~300 m away from the operating airgun array. Thus, the airgun array was immediately powered down to one airgun. The dolphins then proceeded to approach the vessel to within 150 m (~205 m from the active array) and disappeared from view. The dolphins were seen well within the safety radius. Even though the airgun array was being ramped up at the time, it is ***very likely*** that the dolphins were exposed to sound levels ≥180 dB when they dove, because eight airguns were likely firing at the time of the sighting and the water was very shallow.
- A single unidentified dolphin was seen on 1 Feb. at 15:21 GMT in water ~15 m deep. At the time of the sighting, all 20 airguns were firing. The dolphin was initially seen swimming parallel to the *Ewing* at a distance of ~1040 m from the active array, and it also breached once. The closest point of approach of the dolphin to the operating array was ~950 m after the airguns had been powered down to one active airgun. The dolphin was seen well within the safety radius when 20 airguns were firing in very shallow water; thus it is ***very likely*** that the dolphin was exposed to sound levels ≥180 dB when it dove.
- A group of two Atlantic spotted dolphins was seen on 9 Feb. at 16:28 GMT in water ~16 m deep. At the time, all 20 airguns were in operation. The dolphins were seen swimming parallel to the *Ewing* at a distance of ~675 m from the operating airguns, and the airguns were powered down immediately. They approached the vessel to within 200 m (~300 m from the active array) after the airguns had been powered down to one operating airgun. They were also seen breaching once. The dolphins were seen well within the safety radius in very shallow water when 20 airguns were firing; thus it is ***very likely*** that the dolphins were exposed to sound levels ≥180 dB when they dove.
- A single bottlenose dolphin was seen on 17 Feb. at 16:12 GMT in water ~28 m deep. At the time of the sighting, all 20 airguns were firing. The dolphin was seen initially by the bridge crew as it swam across the *Ewing*'s bow at a distance of ~107 m from the operating array. The bridge then notified the MMOs on the flying bridge, and the airguns were shut down. However, several additional shots were fired before the airgun array could be shut down. The dolphin was seen near the *Ewing*'s bow in shallow water when 20 airguns were firing, and it is ***definite*** that the dolphin would be exposed to sound levels ≥180 dB when it dove.
- Later on 17 Feb., at 17:40 GMT, a single unidentified dolphin was seen while all 20 airguns were operating in water ~25 m deep. It was initially seen at a distance of ~2030 m from the operating airguns at which time the array was powered down to one operating airgun. The dolphin subsequently approached the vessel to within 840 m (~915 m from the one active airgun). It was also seen breaching several times. The dolphin was seen well within the safety radius when 20 airguns were firing in shallow water, and it is ***very likely*** that the dolphin was exposed to sound levels ≥180 dB when it dove.

APPENDIX H:
MARINE MAMMAL DENSITY AND EXPOSURE ESTIMATES

TABLE H.1. Sightings and densities of marine mammals during non-seismic periods in water depths <100 m within the Chicxulub study area in the southern Gulf of Mexico, 7 Jan. to 20 Feb. 2005. Non-seismic periods are periods before seismic started or periods >6 h after seismic ended. Survey effort was 1337 km during Beaufort Wind Force (Bf) ≤ 5 and 0 km with Bf ≤ 2.

Species	Number of sightings	Mean group size	Average density[a] corrected for *f* (0) and *g* (0) (# /1000 km^2)	
			Density	CV [b]
Odontocetes				
Delphinidae				
Bottlenose dolphin	4	6.5	15.15	0.72
Atlantic spotted dolphin	4	5.5	12.82	0.72
Unidentified dolphin	3	6.7	11.65	0.76
Total Delphinidae	**11**		**39.62**	**0.55**
Physeteridae	0	—	0.00	—
Ziphiidae	0	—	0.00	—
Mysticetes	0	—	0.00	—
Total Other Cetaceans	**0**		**0.00**	—
Total Cetaceans	**11**		**39.62**	**0.55**

[a] Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).

[b] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation $0.94 - 0.162\log_e n$ from Koski et al. (1998), but likely underestimates the true variability.

TABLE H.2. Sightings and densities of marine mammals during non-seismic periods in water depths 100–1000 m in the southern Gulf of Mexico, 7 Jan. to 20 Feb. 2005. Survey effort was 117 km during Bf ≤ 5 and 0 km with Bf ≤ 2. Otherwise as in Table H.1.

Species	Number of sightings	Mean group size	Average density[a] corrected for *f* (0) and *g* (0) (# /1000 km^2)	
			Density	CV [b]
Odontocetes				
Delphinidae				
Atlantic spotted dolphin	1	10.0	66.58	0.94
Unidentified dolphin	1	2.0	13.32	0.94
Total Delphinidae	**2**		**80.90**	**0.83**
Physeteridae	0	—	0.00	—
Ziphiidae	0	—	0.00	—
Mysticetes	0	—	0.00	—
Total Other Cetaceans	**0**		**0.00**	—
Total Cetaceans	**2**		**80.9**	**0.83**

[a] Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).

[b] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation 0.94 - $0.162\log_e n$ from Koski et al. (1998), but likely underestimates the true variability.

TABLE H.3. Sightings and densities of marine mammals during seismic periods in water depths <100 m in the southern Gulf of Mexico, 7 Jan. to 20 Feb. 2005. Survey effort was 1855 km during Bf ≤ 5 and 0 km during Bf ≤ 2. Otherwise as in Table H.1.

Species	Number of sightings	Mean group size	Average density [a] corrected for *f*(0) and *g*(0) (# /1000 km^2)	
			Density	CV [b]
Odontocetes				
Delphinidae				
Bottlenose dolphin	2	3.0	2.52	0.83
Atlantic spotted dolphin	2	2.0	1.68	0.83
Unidentified dolphin	2	1.0	0.84	0.83
Total Delphinidae	**6**		**5.04**	**0.65**
Physeteridae	0	—	0.00	—
Ziphiidae	0	—	0.00	—
Mysticetes	0	—	0.00	—
Total Other Cetaceans	**0**		**0.00**	—
Total Cetaceans	**6**		**5.04**	**0.65**

[a] Values for *f*(0) and *g*(0) are from Koski et al. (1998) and Barlow (1999).

[b] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation 0.94 - 0.162$\log_e$n from Koski et al. (1998), but likely underestimates the true variability.

TABLE H.4. Estimated numbers of exposures and estimated minimum numbers of individual marine mammals that would have been exposed to seismic sounds ≥160 dB (and ≥170 dB) in the southern Gulf of Mexico if no animals had moved away from the active seismic vessel, 7 Jan. to 20 Feb. 2005. Based on calculated densities[a] in non-seismic periods (Appendix H1). The sound sources were 1 to 20 airguns with total volumes of 80–6970 in^3. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration).

Species/species group	Numbers of exposures [b]		Minimum number of individuals [b]	
Water depth (m)	**<100**		**<100**	
Area in km^2 ensonified to ≥160 dB (≥170 dB)	67,496	(32,739)	22,700	13,672
Odontocetes				
Delphinidae				
Bottlenose dolphin	1023	(496)	344	(207)
Atlantic spotted dolphin	865	(420)	291	(175)
Unidentified dolphin	786	(381)	264	(159)
Total Delphinidae	**2674**	**(1297)**	**899**	**(542)**
Physeteridae	0		0	
Ziphiidae	0		0	
Mysticetes	0		0	
Total Other Cetaceans	**0**		**0**	
Total Cetaceans	**2674**		**899**	

[a] Values for $f(0)$ and $g(0)$ are from Koski et al. (1998) and Barlow (1999).

[b] Slight apparent discrepancies in totals result from rounding to integers.

TABLE H.5. Estimated numbers of exposures and estimated minimum numbers of individual marine mammals that were exposed to seismic sounds ≥160 dB (and ≥170 dB) in the southern Gulf of Mexico, 7 Jan. to 20 Feb. 2005. Otherwise as in Table H.4.

Species/species group	Numbers of exposures [b]		Minimum number of individuals [b]	
Water depth (m)	<100		<100	
Area in km^2 ensonified to ≥160 dB (≥170 dB)	67,496	(32,739)	8,141	(5556)
Odontocetes				
Delphinidae				
Bottlenose dolphin	170	(83)	57	(34)
Atlantic spotted dolphin	113	(55)	38	(23)
Unidentified dolphin	57	(28)	19	(11)
Total Delphinidae	**340**	**(165)**	**114**	**(69)**
Physeteridae	0		0	
Ziphiidae	0		0	
Mysticetes	0		0	
Total Other Cetaceans	**0**		**0**	
Total Cetaceans	**340**		**114**	

[a] Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).

[b] Slight apparent discrepancies in totals result from rounding to integers.

APPENDIX I:

SEA TURTLE DATA

TABLE I.1. Sea turtle sightings made from the *Ewing* in the Chicxulub study area in the southern Gulf of Mexico, 7 Jan. - 20 Feb. 2005. All sea turtles were sighted visually during daylight. All group sizes = 1. One dead sea turtle is indicated as "DE" in the "Initial Behavior" column.

Species	Day in 2004	Time (GMT)	Latitude (°N)	Longitude (°W)	Initial Sighting Distance (m) (airgun array to sighting)	CPA[a] (m) (Distance from turtle to airgun array)	Initial Move-ment[b]	Initial Behav.	Bf[d]	Useable[e] Y or N	Water depth[f] (m)	Vessel Activ.[g]	No. Airguns On	Array Vol. (in^3)	Mitig. (SZ, PD, None)
Unident. sea turtle	11 Jan	14:33:00	21.8701	88.2168	25	109	UN	UN	3	Y	19.3	OT	0	0	None
Loggerhead sea turtle	14 Jan	17:21:40	21.6801	89.5689	50	180	SP	SW	5	Y	25.3	TR	0	0	None
Unident. sea turtle	17 Jan	21:43:18	21.6872	90.1517	307	319	UN	LG	5	Y	33.5	TR	0	0	None
Hawksbill sea turtle	18 Jan	15:44:53	21.6122	90.0787	20	89	UN	LG	6	Y	28	TR	0	0	None
Unident. sea turtle	19 Jan	17:11:48	21.6777	89.9005	1300	1725	NO	LG	4	Y	29.9	TR	0	0	None
Hawksbill sea turtle	19 Jan	18:04:57	21.6661	89.8306	10	97	NO	LG	4	Y	27.3	TR	0	0	None
Hawksbill sea turtle	20 Jan	16:15:00	21.6450	89.9256	20	229	UN	LG	3	Y	26.7	TR	0	0	None
Hawksbill sea turtle	20 Jan	21:55:38	21.7412	89.4758	80	162	NO	LG	3	Y	25.2	TR	0	0	None
Unident. sea turtle	23 Jan	18:16:38	21.5230	89.8433	40	128	UN	UN	1	Y	18	SZ	16-20	6947	SZ
Hawksbill sea turtle	24 Jan	14:57:58	21.4438	89.9876	50	142	NO	LG	4	Y	18	SZ	1	80	SZ
Unident. sea turtle	28 Jan	12:56:34	21.3912	90.7165	40	112	UN	LG	5	Y	24.9	TR	0	0	None
Unident. sea turtle	30 Jan	18:49:18	21.9852	89.1596	138	196	UN	LG	3	Y	39	PD	16-20	6947	PD
Unident. sea turtle	31 Jan	17:42:00	21.7308	89.5774	330	360	UN	LG	4	N	27.4	TR	0	0	None
Hawksbill sea turtle	31 Jan	19:44:21	21.5620	89.5739	140	164	UN	LG	4	Y	20	PD	16-20	6947	PD
Unident. sea turtle	31 Jan	20:34:31	21.5373	89.5261	3	229	UN	SW	5	N	17.7	TR	0	0	None
Hawksbill sea turtle	31 Jan	22:46:00	21.5714	89.3577	25	132	NO	LG	6	N	18.4	TR	0	0	None
Hawksbill sea turtle	2 Feb	19:21:50	21.3494	90.0149	20	107	ST	SW	4	N	25.3	TR	0	0	None
Hawksbill sea turtle	2 Feb	21:30:06	21.3876	89.8328	50	161	NO	LG	4	Y	24	SZ	16-20	6947	SZ
Hawksbill sea turtle	2 Feb	19:08:24	21.3453	90.0340	20	104	ST	SW	4	N	25.5	TR	0	0	None
Hawksbill sea turtle	2 Feb	18:53:56	21.3411	90.0547	50	132	SA	LG	3	Y	25	SZ	16-20	6947	SZ
Hawksbill sea turtle	3 Feb	16:20:00	21.4854	90.1105	200	278	NO	LG	2	Y	21	TR	0	0	None
Hawksbill sea turtle	6 Feb	18:54:00	21.6264	89.9878	10	87	UN	LG	4	N	26.7	TR	0	0	None
Loggerhead sea turtle	9 Feb	14:47:12	21.6830	89.4291	5	1212	NO	DE	4	N	23.4	LS	16-20	6947	None
Unident. sea turtle	11 Feb	14:28:26	21.6254	89.7584	45	187	NO	LG	5	Y	24.5	TR	0	0	None
Hawksbill sea turtle	11 Feb	15:00:41	21.5849	89.7499	35	156	NO	LG	5	Y	21.7	TR	0	0	None
Loggerhead sea turtle	13 Feb	14:36:15	21.5281	89.4950	5	89	ST	SW	5	Y	17.3	TR	0	0	None
Unident. sea turtle	17 Feb	18:39:22	21.6466	89.8154	1017	1063	NO	LG	3	Y	25	PD	4	3005	PD
Hawksbill sea turtle	18 Feb	18:37:06	21.5021	89.7341	100	237	NO	LG	4	N	18.1	RC	0	0	None
Hawksbill sea turtle	18 Feb	19:47:10	21.4398	89.8013	90	328	NO	LG	4	Y	15.8	RC	0	0	None
Hawksbill sea turtle	19 Feb	20:24:04	21.4467	89.5638	3	92	UN	SW	4	N	27.1	MI	0	0	None

[a] CPA is the distance at the closest observed point of approach to the nearest airgun when it was operating. This is not necessarily the distance at which the individual or group was initially seen nor the closest it was observed to the vessel.
[b] The initial movement of the individual or group relative to the vessel. UN=unknown, NO=no movement, SA=swimming away, SP=swimming parallel, ST=swimming toward.
[c] The initial behavior observed. DE=dead, SW=swimming, LG=logging.
[d] Beaufort Wind Force scale (which is not the same as the "Sea State" scale).
[e] Y = yes, N = no; See *Acronyms and Abbreviations* for definition of "useable".
[f] Water depth was recorded for the vessel's location when a sighting was made.
[g] Activity of the vessel at the time of the sighting. LS=operating airguns on a seismic survey line and collecting geophysical data,
PD=power down of airguns, SZ=shut down for turtle in safety zone, OT=other (a period of no seismic activity either during transit or a period after an SZ), MI=Miscellaneous, RC=Recovering equipment, DP=Deploying

TABLE I.2. Sea turtle sightings that prompted power downs (PD) or shut downs (SZ) of the airguns during the Chicxulub seismic survey, 7 Jan. - 20 Feb. 2005. All operations and observations were conducted in daylight; all turtles were seen individually.

Species	Date (2004)	Water Depth (m)	Initial Sighting Distance[a] (m)	Movement[b]	Dove? (Yes/No)	Number & Size (in^3) of Airguns On	Total Airgun Volume (in^3)	CPA (m) to Operating Airguns	Mitigation (PD or SZ)
Unidentified sea turtle	23-Jan	18	40	UN	Y	16-20	6947	128	SZ
Hawksbill sea turtle	24-Jan	18	50	NO	Y	1	80	142	SZ
Unidentified sea turtle	30-Jan	39	138	UN	Y	16-20	6947	196	PD
Hawksbill sea turtle	31-Jan	20	140	UN	Y	16-20	6947	164	PD
Hawksbill sea turtle	2-Feb	25	50	SA	Y	16-20	6947	132	SZ
Hawksbill sea turtle	2-Feb	24	50	NO	Y	16-20	6947	161	SZ
Unidentified sea turtle	17-Feb	25	1017	NO	Y	4	3005	1063	PD

[a] "Initial Sighting Distance" is the first recorded distance from the observation station to the animal; "CPA" is the closest observed point of approach to the operating airgun(s).
[b] Initial movement of group relative to the vessel: UN = Unknown, SA = swim away, NO = no movement.